U.S. DEPARTMENT OF COMMERCE
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PB-26/ 245

Prototype System for Plugging Leaks in Ruptured Containers

Rockwell International Corp, Canoga Park, Calif Rocketdyne Div

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio

Dec 76

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-300	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Prototype System for Plugging Leaks in Ruptured Containers		5. REPORT DATE December 1976 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. J. Vrolyk, R. C. Mitchell, and R. W. Melvold		8. PERFORMING ORGANIZATION REPORT NO. R-9659
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rocketdyne Division Rockwell International Corporation Canoga Park, California 91304		10. PROGRAM ELEMENT NO. 1BB610 11. CONTRACT/GRANT NO. EPA 68-03-0234
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory-Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/12
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

A development program was performed successfully to develop and test a prototype system for temporarily stopping the flow of hazardous materials spilling on land or underwater from ruptured or damaged containers. The prototype system is portable, integrated, and field-operable by one man. It uses foamed-in-place polyurethane rigid foam plugs surrounded by a flexible protective membrane for sealing leaks.

An applicator tip attached to a long handle is placed into the leak. The foam delivery system then is actuated and the foam chemicals, which are stored in a backpack, are automatically mixed and forced through a delivery tube and into the applicator tip expanding it both inside and outside the tank. The foam hardens in a few minutes and locks the plug in place. The applicator is then detached from the delivery system, which then can be refilled with foam chemicals and reused with a new applicator.

The prototype leak-plugging system from this project has been developed to the point that it is now realistic to project practical field use of such a system. A preliminary implementation plan, including recommendations for additional work needed, is outlined. (Mitchell - Rocketdyne)

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Pollution, Accidents, Hazardous Materials, Transportation, *Sealants, *Chemicals, *Leakage	Hazardous Chemical Spills, Prevention of Water Pollution, *Plugging Chemical Leaks	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 110
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A06 - A01

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5591 Region No. 5-11

PB 267 245

EPA-600/2-76-300
December 1976

Environmental Protection Technology Series

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SPRINGFIELD, VA. 22161

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EPA-600/2-76-300
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PROTOTYPE SYSTEM FOR PLUGGING LEAKS IN RUPTURED CONTAINERS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes the development of a prototype system to temporarily stop the flow of hazardous materials spilling on land or under water from ruptured or damaged containers. The system uses foamed-in-place polyurethane foam plugs surrounded by a flexible protective membrane for sealing leaks. The plugging device is portable, integrated and field-operable by one man. By stopping or restricting the release of hazardous materials from ruptured containers, the environmental effects of such spills are minimized and the clean-up operations are greatly facilitated. This report should be of value to Federal, state and local government personnel as well as to individuals from the chemical process and transportation industries who are involved in responding to accidental releases of hazardous substances. Information on this subject beyond that supplied in the report may be obtained from the Oil and Hazardous Materials Spills Branch (IERL), Edison, New Jersey 08817.

David G. Stephan
Director
Industrial Environmental Research Laboratory
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ACKNOWLEDGEMENTS

The support of the project by the U. S. Environmental Protection Agency and the interest and involvement exhibited by the Project Officer, Ira Wilder, are acknowledged with sincere thanks.

This project was conducted in the Advanced Programs Department at Rocketdyne with Dr. B. L. Tuffly, as Program Manager, responsible for overall administration, and Dr. R. C. Mitchell, as Project Engineer, responsible for the technical content and conduct of the program. Messrs. J. J. Vrolyk and R. W. Melvold performed most of the technical work on the project. Other members of the project team were R. Doubleday, C. L. Hamermesh, W. Unterberg, and E. Witucki.

SECTION 1

INTRODUCTION

Tremendous quantities of chemicals are continually produced in the United States and then shipped to various locations for use. Many of these chemicals create environmental and public health hazards when introduced into natural waters. The likelihood of accidental release to watercourses is obviously increased by the many sequences involved in the production, transfer, shipping, unloading, and ultimate utilization of the chemicals. While it is not at all surprising that spills do occur, there must be continued vigilance to reduce their number and severity.

Hazardous materials spills take place in a variety of ways. Dramatic spills occur when containers are violently ruptured (sometimes accompanied by fire or explosion), and large quantities of a hazardous material are spilled almost instantaneously. A less catastrophic spill results when the container maintains its integrity, but suffers enough damage to allow leakage of the hazardous material at a moderate rate. The leaking chemical can enter the watercourse either directly (for example, as the result of a barge accident or a land-based container falling into the water) or by flowing or being washed into a drainage channel or percolating into the ground water supply.

Countermeasures to neutralize or treat hazardous chemicals that have already entered the waterway may require hours or days to be initiated and may involve the very difficult problem of handling large volumes of water. There is a vital need for systems that can stop leaks and thereby prevent further dispersion of spilling hazardous chemicals. Reference 1 presents an excellent overview of the problem of controlling hazardous material spills.

The feasibility of the concept of using foamed plastic to plug leaking chemical containers was demonstrated during a previous project (Contract No. 68-01-0106) for the U. S. Environmental Protection Agency (Ref. 2, 3). The objective of the current program was to develop the concept into a practical prototype system for plugging leaks.

The leak-plugging system consists of two major components: a foam supply device (which provides for storage of foam constituents, plus mixing, transfer, and control of the foam) and an applicator (which places the foam in the opening of the ruptured container in such a way as to plug the leak, while minimizing interferences from the gushing chemical stream, chemical action of the spilling material, and the physical characteristics of the rupture). Development work was done on both components. Various aspects of operator safety and ease of use were considered. The product of this research is an integrated, one-man, field-operable device that can be used by a relatively unskilled operator wearing protective clothing.

SECTION II

SUMMARY

A program was performed successfully to develop and test a prototype system for stopping the flow of hazardous materials spilling on land or underwater from ruptured or damaged containers. The prototype system is portable, integrated, and field-operable by one man. It seals leaks, using foamed-in-place polyurethane rigid foam plugs covered with flexible protective membrane.

The leak-plugging system consists of two major components: a foam supply device (which provides for storage of foam constituents, plus mixing, transfer, and control of the foam) and an applicator (which places the foam in the opening of the ruptured container in an effective way to plug the leak. The applicator has a handle with an actuating device on one end and an applicator tip on the other end.

The tip is thrust into the hole to be plugged and the delivery system is activated by the operator. This causes two urethane foam components to be released from their pressurized containers, automatically mixed together as they flow, and forced into the applicator tip while it is being held in the hole. Expansion of the foam causes the applicator tip to expand both inside and outside the tank wall simultaneously, filling the hole and stopping the leak. About a minute after the start of this expansion, the foam has become hard enough to permit removal of the handle and the delivery tube; the plug is then self-supporting.

The delivery system then can be disconnected, recharged with foam components, and attached to a new applicator tip (in the field), making the system ready for a repeat plugging operation, if required. This repeated use can continue over many cycles.

Particular attention was given during the prototype development work to considerations of safety, ease of use, lightness of weight, rapid-response capability, and other features that are important in a practical operational system. A broad range of goals for system operating characteristics were listed at the beginning of this effort to serve as guidelines for prototype system development. Each of these goals was achieved, to at least a sufficient extent, to permit satisfactory use of the prototype leak-plugging system.

The prototypes are easily portable and practical for one-man field operation with no requirement for external power, motors, or batteries. The prototypes cause no secondary pollution problems and permit salvage of hazardous chemical remaining in the tank. The systems normally provide sturdy, long-term plugging with complete or nearly complete blockage of the leaking chemical. They provide rapid response, and would have reasonable cost in production quantities.

The leak-plugging performance is unaffected by dry, wet, or dirty tank surfaces. The system has considerable flexibility in hole size, shape, and location. Successful plugging tests have been made with holes from 2.5 to 10 cm (1 to 4 inches) across and cracks as narrow as 1.3 cm (1/2 inch). It is expected that the present leak-plugging concept can be used over even wider ranges of leak sizes, e.g., holes from about 1 to 30 cm (1/2 to 12 inches) across, and cracks as thin as 0.3 cm (1/8 inch). The prototype system can be used to plug leaks against liquid heads as high as those normally encountered in tank cars. The system has wide temperature tolerance: about 10 to 38 C (50 to 100 F) for the foam and hardware storage, and operation down to at least 0 C (32 F) provided the system is not exposed to the colder temperatures for more than a brief period before use.

The prototypes are sufficiently safe and easy to use for operation by relatively untrained personnel wearing protective clothing. There are only a small number of chemicals expected to be designated as "hazardous substances" which are not feasible for leak-plugging with the system. Limitations on applicability are primarily the result of very high vapor pressure, excessive risk of exposure by operator, or severe chemical reactivity.

The prototype leak-plugging system from this project has been developed to the point that it is now realistic to project practical field use of such a system. A preliminary implementation plan is outlined.

This report (R-9659) was submitted by the Rocketdyne Division of Rockwell International in fulfillment of Contract 68-03-0234, under the sponsorship of the U. S. Environmental Protection Agency.

SECTION III

CONCLUSIONS

1. There is a vital need for systems that can prevent dispersion of a hazardous chemical. It is far better and easier to prevent a hazardous chemical from entering a waterway than it is to attempt to remove it after entry.

2. Two successful prototype leak-plugging systems have been developed and tested. Both systems can plug leaks of hazardous materials spilling on land or under water from ruptured or damaged containers.

3. The prototypes are easily portable and practical for one-man field operation with no requirement for external power, motors, or batteries.

4. The prototypes cause no secondary pollution problems and permit salvage of hazardous chemical remaining in the tank.

5. The systems normally provide sturdy, long-term plugging with complete or nearly complete plugging.

6. The systems provide rapid response (less than 1 minute for the actual plugging, 2 to 3 minutes including unpacking and preparation).

7. The systems are sufficiently safe and easy to use for operation by relatively untrained personnel wearing protective clothing.

8. The system has reasonable cost (about $900 in direct cost to duplicate prototypes, less to make production models).

9. There are only a small number of hazardous chemicals which are not feasible for leak-plugging with the system. Limitations on applicability are primarily the result of very high vapor pressure, excessive risk of exposure by operator, or severe chemical reactivity.

10. The leak-plugging performance is unaffected by dry, wet, or dirty tank surfaces.

11. The system has considerable flexibility in hole size, shape, and location. Successful plugging tests have been made with holes from 2.5 to 10 cm (1 to 4 inches) across and cracks as narrow as 1.3 cm (1/2 inch). It is expected that the present leak-plugging concept can be used over wider ranges of leak sizes, e.g., holes from about 1 to 30 cm (1/2 to 12 inches) across, and cracks as thin as 0.3 cm (1/8 inch).

12. The prototype system can be used to plug leaks against liquid heads as high as those normally encountered in tank cars.

13. The system has wide temperature tolerance: about 10 to 38 C (50 to 100 F) for the foam and hardware storage, and operation down to at least 0 C (32 F), provided the system is not exposed to the colder temperatures for more than a brief period before use.

14. The prototype leak-plugging system from this project has been developed to the point that it is now realistic to project practical field use of such a system.

15. Wide-scale field use of such a system (or any other system which mitigates the potential effects of hazardous materials spills) will occur only if there is a clear requirement for purchase and deployment of such equipment. Legislation or regulations probably will be required to motivate implementation.

SECTION IV

RECOMMENDATIONS

1. It is recommended that additional work be performed to prepare the way for operational use of the leak-plugging system, through developing the basis for two essential subsequent actions: (a) regulations which establish a definite requirement for the type of environmental protection afforded by this device, and (b) production development by interested manufacturing companies.

2. It is recommended that the additional work include:

   a. Establishing data on and improving the reliability of the system under difficult conditions (high heads, large and irregular holes, low temperatures)

   b. Tests to establish better chemical compatibility data for a variety of applicator tip membranes under realistic stress-strain conditions

   c. Further low-temperature testing and development

   d. An evaluation of cost-benefits of deployment of leak-plugging systems with three different degrees of proximity to an accident site (on the vehicle, at the nearest city, and at a central location within the EPA region in which the accident occurred)

   e. Assessment of the reactions to and requirements of personnel and organizations which may be using the device

   f. Modest field testing and demonstration to personnel from transportation and emergency response organizations

SECTION V

DEVELOPMENT WORK

This section describes the evolutionary development work which resulted in the prototype system delivered at the end of the program. Section VI describes the final prototype system in detail. There were many concepts and devices considered and tested during the development program. Although many of these were later modified or superseded, they are described in this section (V) for documentation and for future reference. Some of these concepts may be useful in future development of leak-plugging systems for various applications.

BACKGROUND WORK

Most of the exploratory work on the previous project (Ref. 2, 3) used applicators that placed a polymeric foam directly in contact with the leaking chemical. Initially, attempts were made to discharge foam directly from a generator into a hole to plug it. Although this technique was successful with leaks under very low liquid head, it is totally impractical when there is significant internal pressure. The velocity and momentum of a leaking fluid under even moderate driving pressure are substantial; e.g., for a 1.8-m (6-foot) driving head, the velocity of an ideal liquid spilling from a hole is about 6.1 m/sec (20 ft/sec); the horizontal force that must be applied by an operator to hold a plug in place over a 10-cm (4-inch) diameter hole is about 147 Newtons (33 lbf).

The next stage in the evolution of an applicator was the use of simple cup-like structures or an open-ended cylinder with a piston to hold the foam and to physically force it through a hole against the flow of the leaking liquid. The feasibility of the concept was demonstrated even with such simple applicators. Successful leak-plugging tests were performed on 7.6-cm (3-inch) diameter holes in 232-liter (55-gallon) containers [about 0.9 m (3 feet) of head] with water, benzene, and methanol. Tests were conducted with leaking containers both submerged in water and out of the water (Ref. 2, 3).

A number of problems were identified after these early tests. One problem was the variability in the leak-sealing performance of a given foam and applicator device. Direct contact between the chemical stream and the foam, both before and after setting, introduced many variables and possibilities for failure in the formation of a stable foam and the plugging of the leak. The variations appeared to be the result of complex interfering actions of the gushing liquid stream against the foam, foam component composition and mixture ratio, mixing efficiency, initial temperatures of the components, ambient temperature, and techniques of application. Each factor could have an appreciable effect on the leak-plugging behavior.

It was found to be necessary for the foam to expand both inside and outside the leaking container in order to effect a reliable seal. This configuration results in a structural bridge and a secure plug.

Considerable work was done under the previous project (Ref. 2, 3) to screen and evaluate a number of potential sealant materials. These included various urethane foam systems; polystyrene and polyvinyl acetate instant foams; filled and unfilled epoxy systems; and polysulfide, butyl, neoprene, and silicone rubber systems. The most-promising results were obtained with the urethane foams. The better urethane systems, of the several tested, provided excellent strength and physical properties, good adhesion to solid surfaces, and satisfactory chemical resistance to a broad range of hazardous chemicals. The two components of these urethane systems react to yield crosslinked products, and these crosslinking reactions are base catalyzed. Acids interfere with the reaction and attack the crosslinked product. Therefore, some hazardous materials, especially acidic ones, can interfere with the curing of a urethane foam or even attack a cured foam plug.

In this developmental study, it was necessary to consider the range of practical applications for the leak-plugging device. A preliminary study was made (Ref. 3) to define an envelope of applicability in terms of characteristic parameters of a leaking container (size of hole, size of container, and liquid head in the container) within which leak plugging should be considered. It is obvious that a very large hole in a small container will result in a complete loss of the contents before corrective action can be taken. Therefore, there is an upper limit on rupture or hole size (a function of container size, liquid head, and allowable response time) which it is practical to consider. Another boundary condition arises from considering the practical limits of human strength. A system that involves stopping the flow of a leaking fluid generally will require the operator to exert a force sufficient to hold a plug in place against the hydraulic pressure of the leak for a few seconds. It was concluded that the region of practical applicability is broad enough and the potential capability of the leak-plugging system is great enough to justify its development for operational use. Additional analysis of the range of practical applications was made during this project and is described in Section VI, Operating Characteristics, (Characteristic 14).

PRELIMINARY DEVELOPMENT TESTS

The first series of tests made at the beginning of this program were leak plugging tests with direct application of urethane foam to a chemical leak (without any restraining or auxiliary hardware). The foam was delivered to the leak by using a commercially available system (Autofroth gun manufactured by Olin Corporation) normally used for producing rigid urethane foam for foamed-in-place thermal insulation. This urethane foam gun was fed from pressurized cylinders containing the two foam components.

1. Plugging of holes in an empty container. This was very successful only when the hole was just above a horizontal platform on which the chemicals could briefly rest while expansion was taking place.

2. Plugging of holes in a 232-liter (55-gallon) container filled with water. This was entirely unsuccessful because the foaming chemicals would not remain in the vicinity of the hole long enough to form a cured plug. The foam would be swept outward by the exiting water stream, or, when it did penetrate the water stream to the inside of the tank, would quickly rise to the surface of the water in the container due to the very high buoyant forces exerted by the liquid.

From these tests and testing performed during the previous program (Ref. 3), it was concluded that the best way to plug leaking chemical containers is to provide a system where the following sequence of events will take place:

1. Stop the great bulk of the flow utilizing mechanical means with assistance from an operator.

2. Introduce foam which expands against the hydrostatic pressure and is mechanically constrained to prevent movement caused by buoyant forces.

3. Provide a physical barrier to separate the curing foam from direct contact with the leaking chemical.

4. Allow time for foam to set in such a way that it provides a self-locking plug; then the operator can release any required holding force that he is providing.

5. At some point during the above, the foam should fill all remaining holes (as far as practical), thus providing a tight seal.

Preliminary tests were made of the "expanded-balloon" concept (Fig. 1) devised at the end of the previous program (Ref. 3). In the foam-filled balloon concept, an expandable rubber sleeve (or balloon) is attached securely to the end of a foam supply system. The end of the delivery tube with the balloon is pushed through the opening in the leaking container. The premixed foam components are injected into the balloon through the tube (both through the end and through selected circumferential holes). As the foam expands, the foam-filled balloon expands on both sides of the hole to form a mechanical bridge, and this securely holds the plug in place.

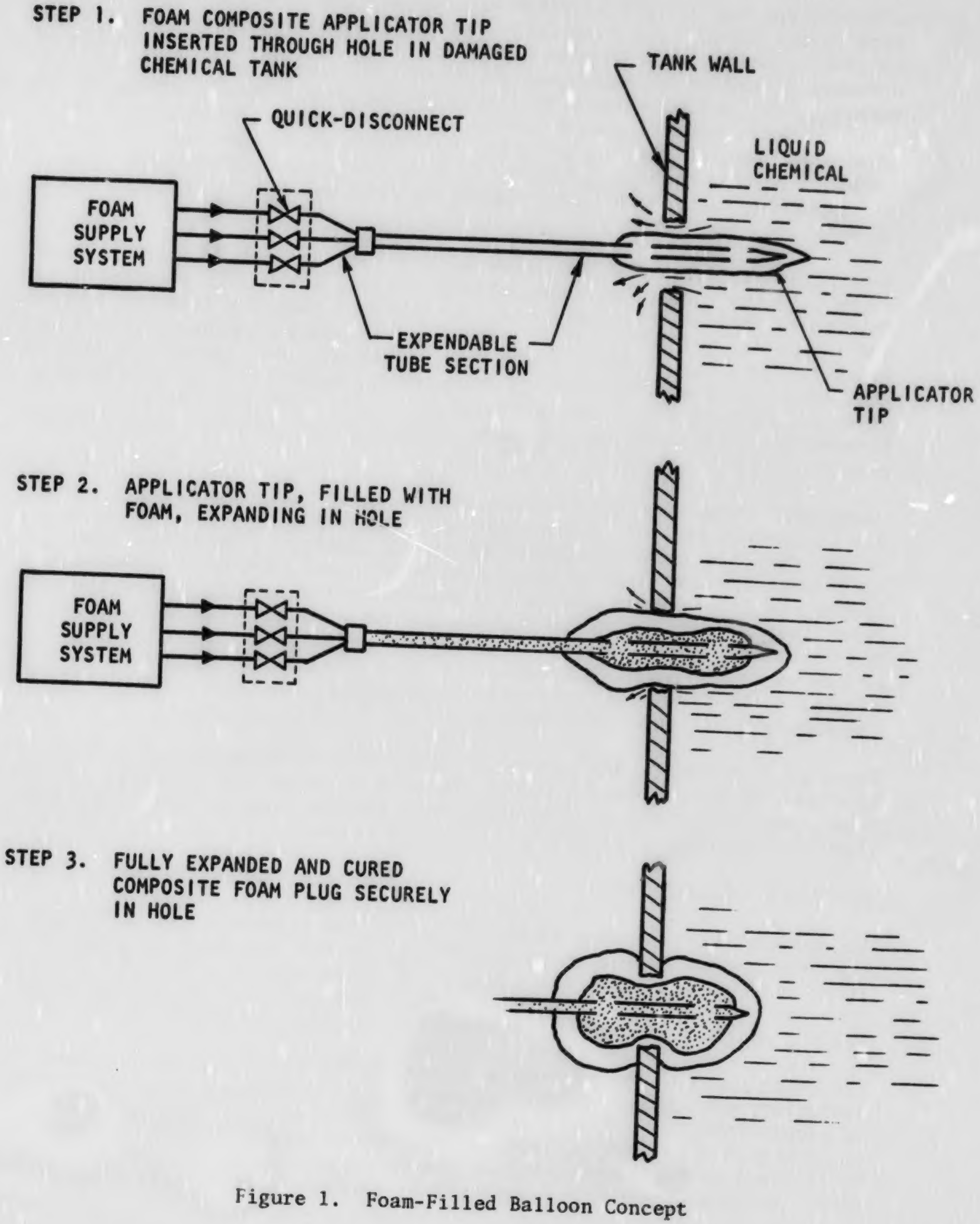

STEP 1. FOAM COMPOSITE APPLICATOR TIP INSERTED THROUGH HOLE IN DAMAGED CHEMICAL TANK
TANK WALL
QUICK-DISCONNECT
LIQUID CHEMICAL
FOAM SUPPLY SYSTEM
EXPENDABLE TUBE SECTION
APPLICATOR TIP
STEP 2. APPLICATOR TIP, FILLED WITH FOAM, EXPANDING IN HOLE
FOAM SUPPLY SYSTEM
STEP 3. FULLY EXPANDED AND CURED COMPOSITE FOAM PLUG SECURELY IN HOLE

Figure 1. Foam-Filled Balloon Concept

A simple version of such a system was constructed in which polyurethane foam passed through a 1.3-cm (1/2-inch) diameter mixing tube, through a quick-disconnect, then through a check valve, and finally into the tip of a rubber sleeve or balloon which surrounded the above hardware. The rubber sleeve and assembly were then inserted into a round, 3.8-cm (1-1/2-inch) diameter hole in a tank containing water under 0.6 meter (2 feet) of water pressure. After insertion, the froth gun trigger was pulled immediately (for about 5 seconds), filling the rubber sheath with foam and expanding the sheath so it filled the hole and stopped the main flow of water.

Good plugs were obtained, although small trickles remained (with leakage rates of a few cc/min, as compared with several liters/min originally). This small residual trickle was due to the fact that the foam was restricted inside the rubber sheath and could not expand to conform with all the irregularities in the edge of the hole. However, this technique, even in this form, was very effective in stopping the major flow, in providing a physically strong plug, and in providing a plug that has a barrier between the tank fluid and the foam, thus greatly reducing compatibility problems.

There were three difficulties with the expanded-balloon concept. There was the possibility of tearing the rubber on jagged edges of the hole before the foam had cured enough to prevent leakage. There was some difficulty in inserting the collapsed balloon into the hole, since it lacked rigidity. There was some tendency for the foam to expand preferentially either inside or outside the tank, rather than both inside and outside the tank; this was caused by the fluid forces on the foam before curing. Subsequent applicator development efforts concentrated on retaining the attractive features of the expanded-balloon concept while overcoming these three limitations.

Parallel, related development work was devoted to both the applicator and the foam supply device. Although the work on these two components of the leak-plugging system was interdependent, the development of each will be described separately in the following subsections.

APPLICATOR DEVELOPMENT

The applicator is considered to consist of two elements: an applicator tip (which places the foam in the opening of the container in a way to effectively plug a leak) and a handle or probe (which is both a delivery tube for the foam and a long handle which the operator can use to place the tip into the rupture while standing some distance away).

The development of an improved applicator went through a considerable evolution, with many different concepts and variations conceived, built in simple form, tested, and discarded or modified. An important conclusion from this work is that the applicator should provide for complete or at least partial separation of the leaking chemical and the curing foam. Various combinations were tested using rubber or plastic bags or membranes to separate the foam and chemical or using solid, porous, slotted, and other perforated rubber plugs and cones of various types with foam injected inside and moving to the outside.

The types of applicators devised and tested later in the development program greatly reduce or eliminate any compatibility problems between the urethane foam and the leaking hazardous chemical. This is realized by inherent features in the applicators which minimize or eliminate any direct contact between the urethane foam and the hazardous chemical, as described later in this subsection. This conceptual improvement eliminates most of the uncertainty and inconsistency previously experienced in plugging leaks with direct contact between the curing foam and the leaking chemical.

Before describing various types of applicators which were tested, some definitions will be made for clarification. The type of flexible polyurethane material known commonly as "foam" (used in mattresses and pillows) is actually a reticulated or open-cell foam (i.e., the cells are interconnected). This can be contrasted with a closed-cell material known as rigid polyurethane foam (used for thermal insulation and flotation devices in industry). This closed-cell material is usually produced at the point of use by mixing two liquid components together. For example, the urethane foams used in this project consist of a polyol and an isocyanate, each containing a certain quantity of foaming agent such as Freon 11 or Freon 12. To distinguish between the two types of foam in the following discussion, reticulated foam will be referred to as "sponge," while closed-cell foam will be referred to simply as "foam."

Expanding Rubber Cone Applicator

This device consists of a truncated cone of solid rubber with a threaded rod down the axis of the cone, as shown in Fig. 2. Twisting of the handle forces the two ends together, causing the diameter to increase by as much as 50 to 100 percent (provided expansion is not restricted).

This device is very effective in sealing fairly round holes, even before application of a foam. For irregularly shaped holes it cannot, of course, seal the hole without foam, but it accomplishes two things: (1) it provides a firm hold on the tank at the hole edge so that a foam-dispensing device can be fastened to it to seal the remaining openings around the edge of the hole with foam and (2) it stops a major portion of the flow through the hole, the amount depending upon the hole shape. Thus, the initial insertion of this device utilizing a long pole permits immediate reduction of the main leakage flow.

Two additional versions (Fig. 3 and 4) of the above device were built which incorporated the use of (1) foam, (2) a thin plastic barrier, and (3) a plastic sponge. These all combine to fill and stop leakage through the spaces between the irregular peripheral edge of the hole and the outer surface of the cone. These features are illustrated in Fig. 3. The assembly is first forced into the hole and immediately expanded by

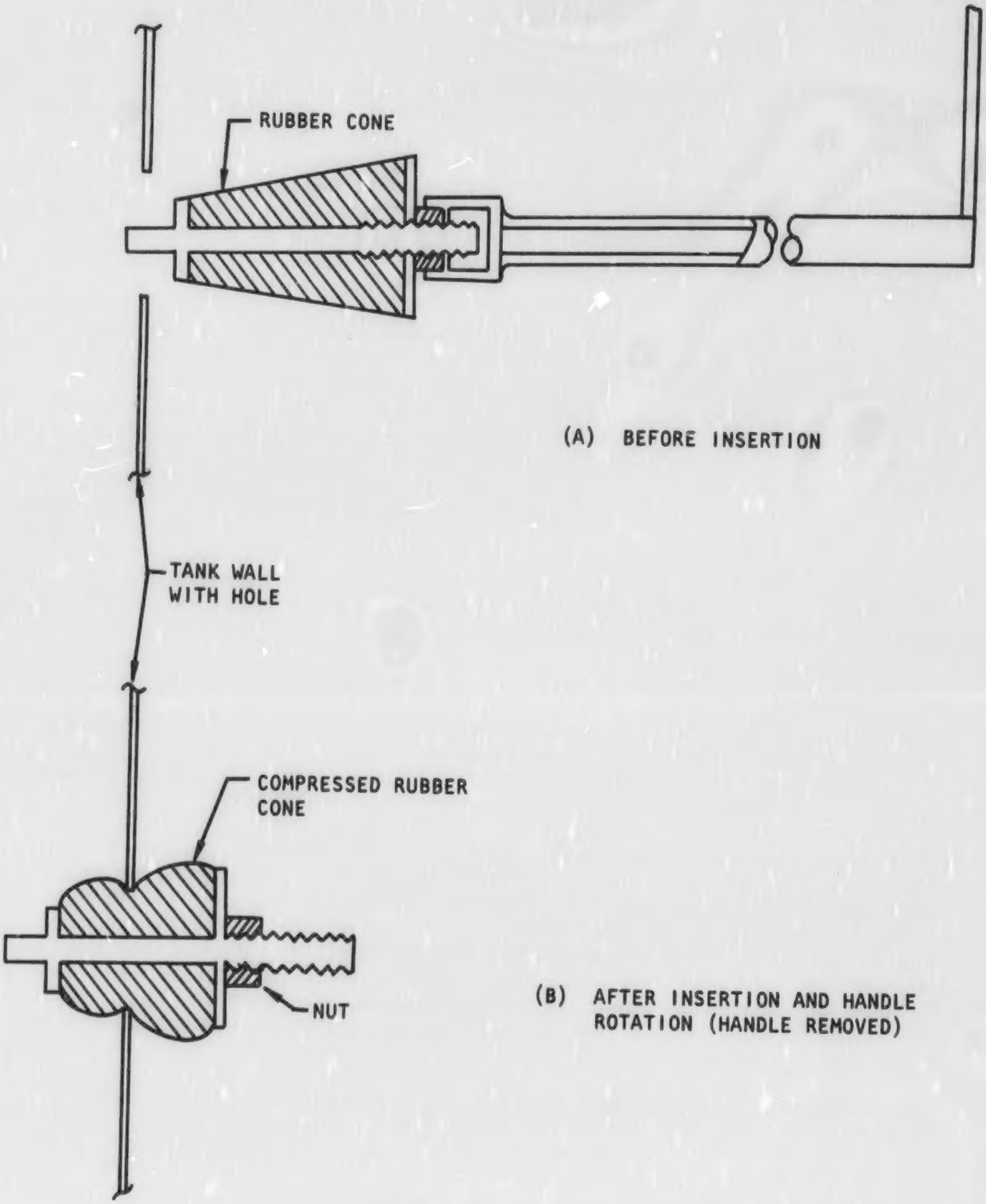

RUBBER CONE
(A) BEFORE INSERTION
TANK WALL
WITH HOLE
COMPRESSED RUBBER
CONE
NUT
(B) AFTER INSERTION AND HANDLE
ROTATION (HANDLE REMOVED)

Figure 2. Expanding Rubber Cone Plug

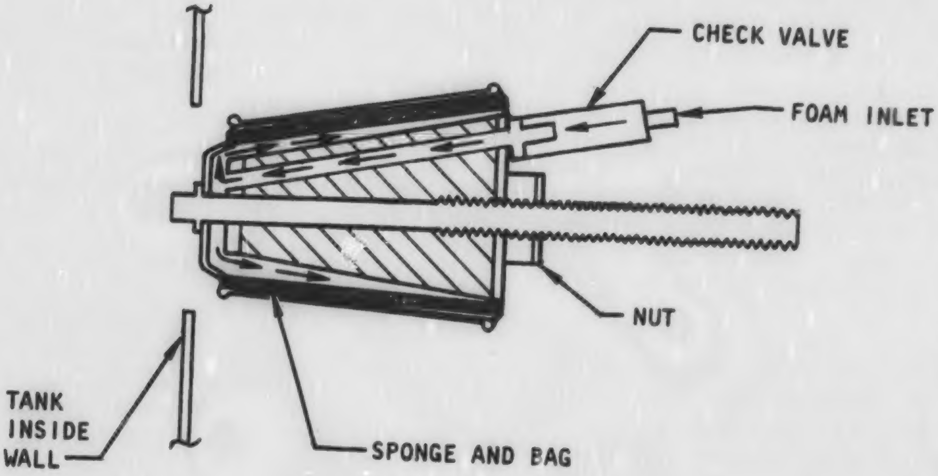

CHECK VALVE
FOAM INLET
NUT
TANK INSIDE WALL
SPONGE AND BAG

Figure 3. Expanding Rubber Cone Applicator (Before Use)

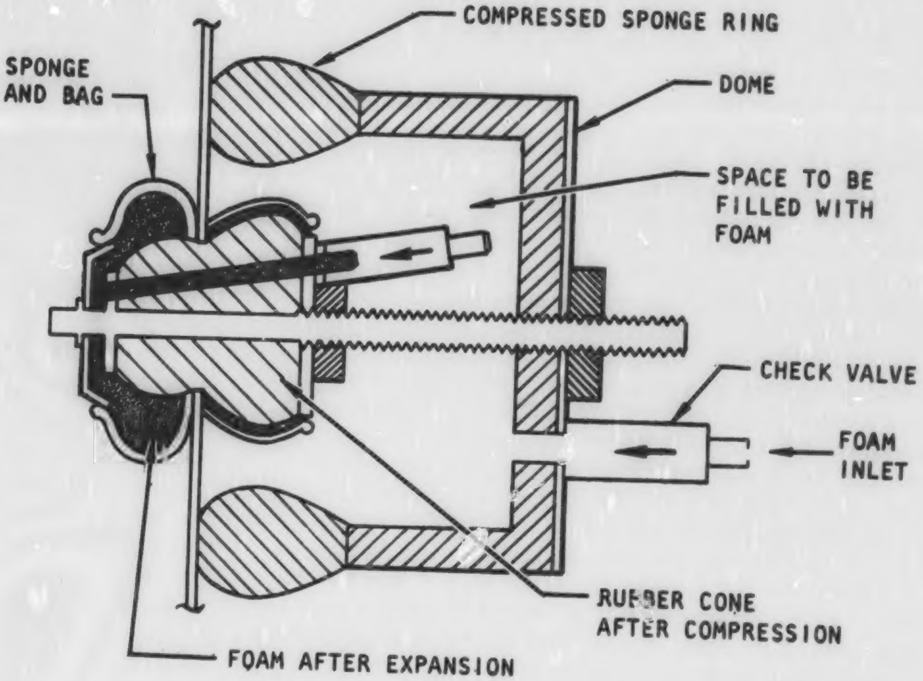

COMPRESSED SPONGE RING
SPONGE AND BAG
DOME
SPACE TO BE FILLED WITH FOAM
CHECK VALVE
FOAM INLET
RUBBER CONE AFTER COMPRESSION
FOAM AFTER EXPANSION

Figure 4. Expanding Rubber Cone and Dome Applicator (After Use)

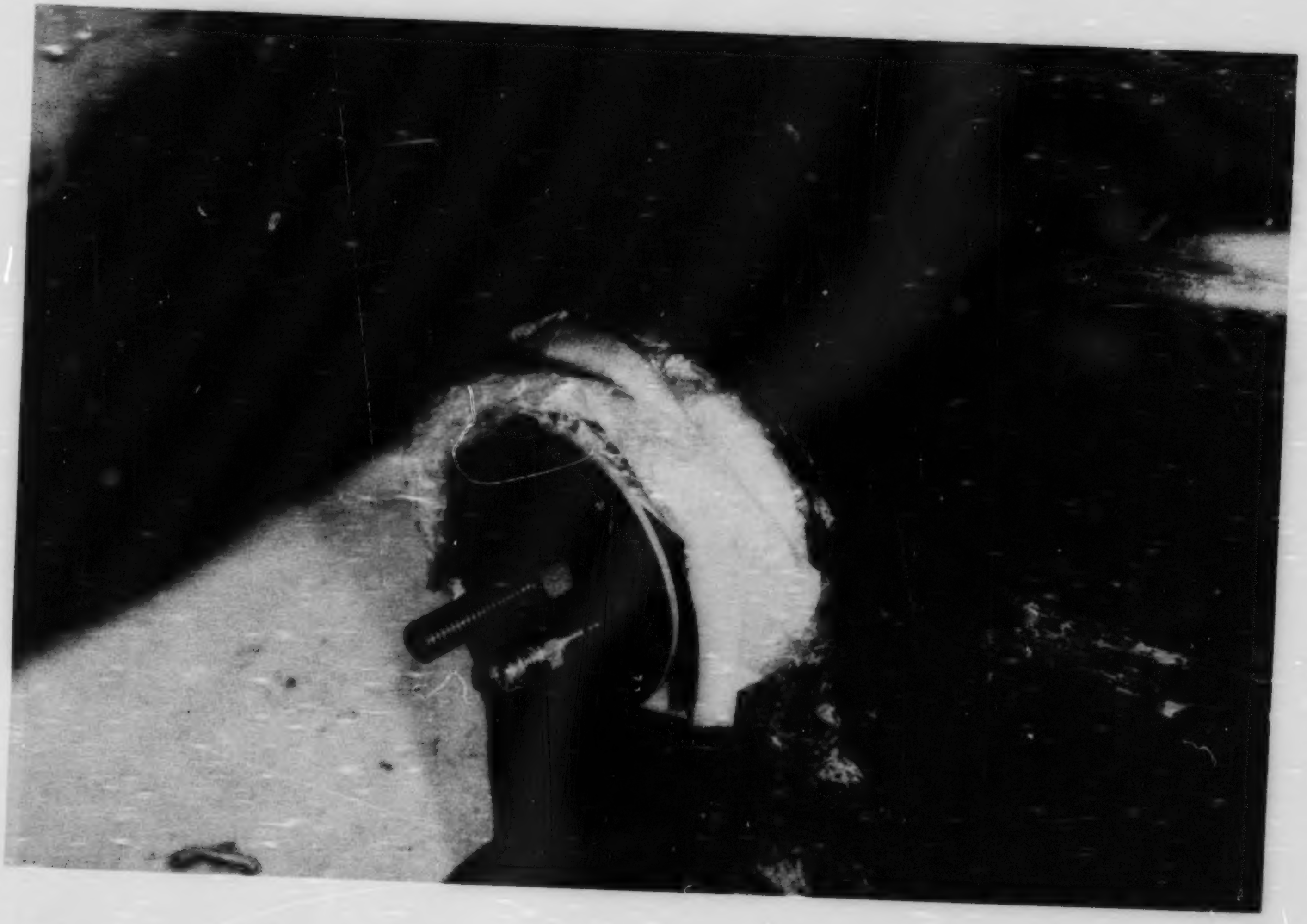
tightening the nut. This stops most of the flow and locks the rubber cone in the hole as shown in Fig. 3. The foaming mixture is then shot into the plug using a foam-delivery system (not shown). The foam expands, pushing the plastic bag and sponge against the inside of the tank and blocking the openings remaining around the edges of the rubber plug. When the foam hardens, it furnishes additional strength to the plug system. If the hole is so extremely jagged that the above is not adequate, the dome shown on the right of Fig. 4 is added. The sponge ring is compressed after the foam has been introduced into the dome but before this foam can harden. This forces the partially cured foam into the remaining holes to effect a more complete seal.

A number of minor variations of the expanding-rubber-cone applicator were tested in an effort to improve the plugging of holes with very irregular edges (the best of these alternatives is shown in Fig. 3, 5, and 6). All of the types of rubber-cone applicator tips gave perfect seals in nearly round holes. Sealing difficulty increased as the irregularity of the holes increased; in even the worst cases, however, about 98 percent of the flow was stopped. Figures 5 and 6 show a good sealing test, as viewed from the outside of the tank and from above the tank wall.

A more sophisticated device using a dome arrangement, as depicted in Fig. 4, was built and used in checkout tests. Operation was easy and leak plugging was essentially complete (i.e., only a very small leak remained). The basic hole diameter was about 6.4 cm (2-1/2 inches), with saw cuts radiating outward about 2 cm (3/4 inch) beyond the outside edge. The tests were made with water flowing with a head of 1.2 m (4 feet).

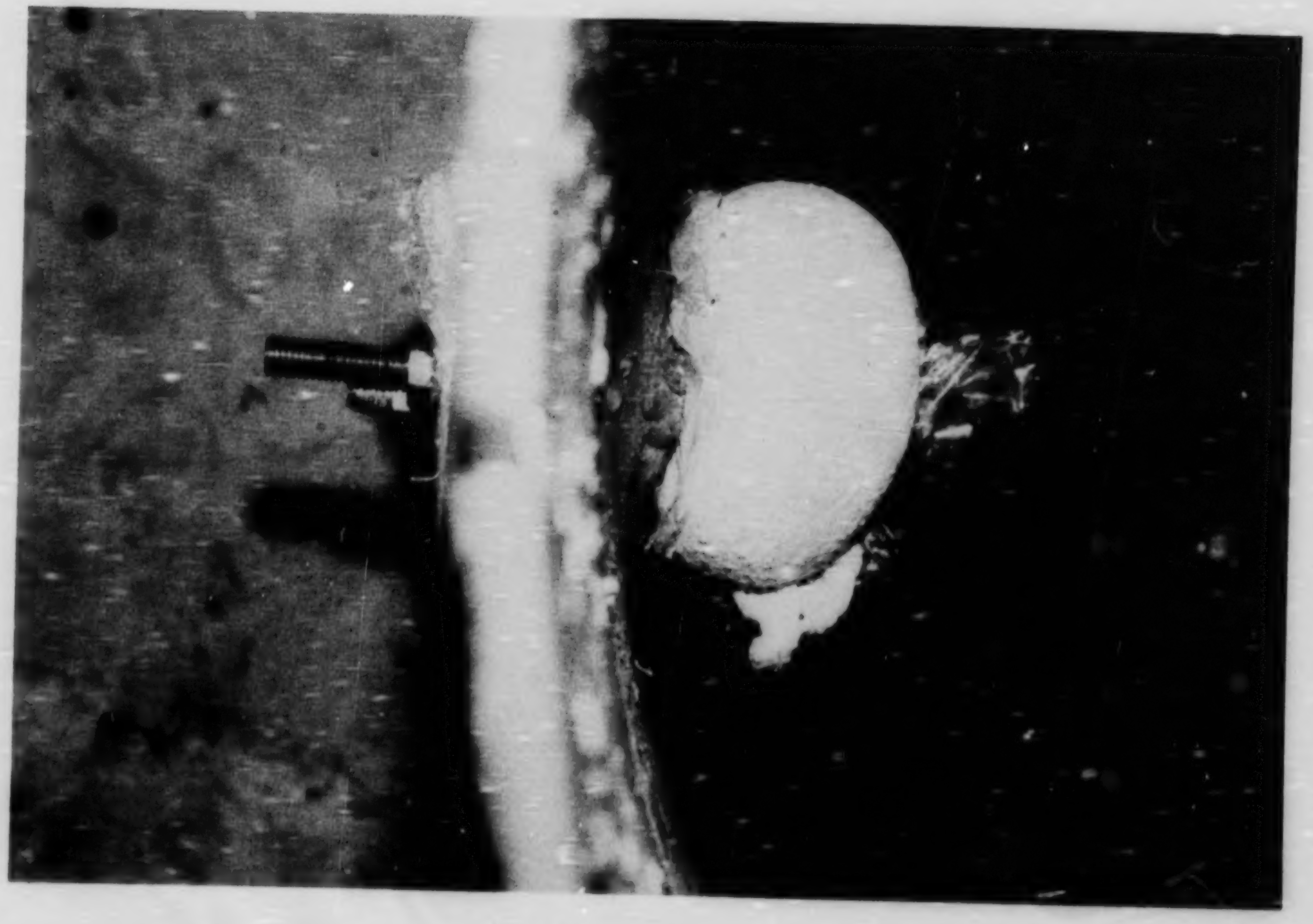
The results of this test showed that approximately 90 percent of the flow was stopped by the rubber cone alone. The remaining flow was reduced by about two-thirds after the rubber cone was expanded by compression. Flow was reduced to a small trickle after introduction of the foam into the rubber cone. Addition of the dome filled with foam on the outside reduced the flow to about one drop per second.

The above scheme has several advantages from an operational standpoint in that the plugging process can be divided into stages separated by time intervals which are flexible and which can be varied in accordance with the demands of the emergency situation existing in the field. Thus, only the rubber cone with mechanical expansion could be initially used to very quickly stop most or all of the flow immediately. If leakage persisted, the foam gun would be attached and the bag and sponge would be expanded with foam on the inside of the tank. Another evaluation period could then be used to determine whether still more sealing was required. If so, the dome would be attached, clamped tightly against the tank by tightening the nut, and the dome subsequently filled with foam, with the possibility that a complete seal would then be obtained.



5DZ16-12/5/73-S1F

Figure 5. Photograph of Plug With Expanding Rubber Cone Applicator



5DZ16-12/5/73-S1C

Figure 6. Photograph of Plug With Expanding Rubber Cone Applicator

The expanding-rubber-cone type of applicator, described in this subsection, has many attractive features. However, it was not chosen for the final prototype development for the following reasons:

1. Initial insertion requires a twisting movement of the operator simultaneously with a thrusting force to hold back the fluid pressure. This is more difficult than just holding an applicator in the hole, which requires thrust only.
2. If the device is used underwater, a twisting force may be very difficult to apply unless the operator has a stationary place to stand.
3. Tests showed that the dome concept could not be made to seal as completely as first expected, so the advantage of this method over the one finally chosen for development was questionable, while its complexity and cost were much greater.

Toggle and Dome Applicator

This applicator is similar to the expanding-rubber-cone applicator described in the preceding subsection in that it attempts to seal the hole by providing both a plug locked in the hole and a dome full of foam on the outside.

The toggle is shown extended in the upper view of Fig. 7. The toggle is first folded parallel to the handle and thrust into the hole to be sealed. The toggle then opens since it has an internal spring (not shown) which causes it to extend as soon as it is free of the hole through which it entered. The operator then pulls on the handle while pushing the dome toward the hole as rapidly as possible. The first portion of the dome to contact the tank wall surrounding the hole is a cylinder of polyurethane sponge. This material is very easily compressed and will conform to irregularities in the tank surface surrounding the hole. When the operator has used his force to press the dome against the tank, he rotates the dome clamp, thus securing the dome in place.

The foam gun is then triggered (not shown), causing foam mix to flow into the dome space between it and the thin plastic bag. The foam expands, pushing the bag and the slip ring ahead of it, and fills the space in the dome, the form ring, and finally the hole in the tank. The plastic bag is finally stretched by the expanding foam into a mushroom-like shape, thereby locking the foam plug in place and sealing the hole (Fig. 7, bottom view). The plastic bag serves two purposes:

1. It provides, at least initially, a barrier between the foam and the liquid in the tank, thereby eliminating possible compatibility problems between the foam chemicals and the tank chemicals.
2. It prevents the foam from breaking off and floating to the tank fluid surface after entering the tank at the h[illegible]. Until the

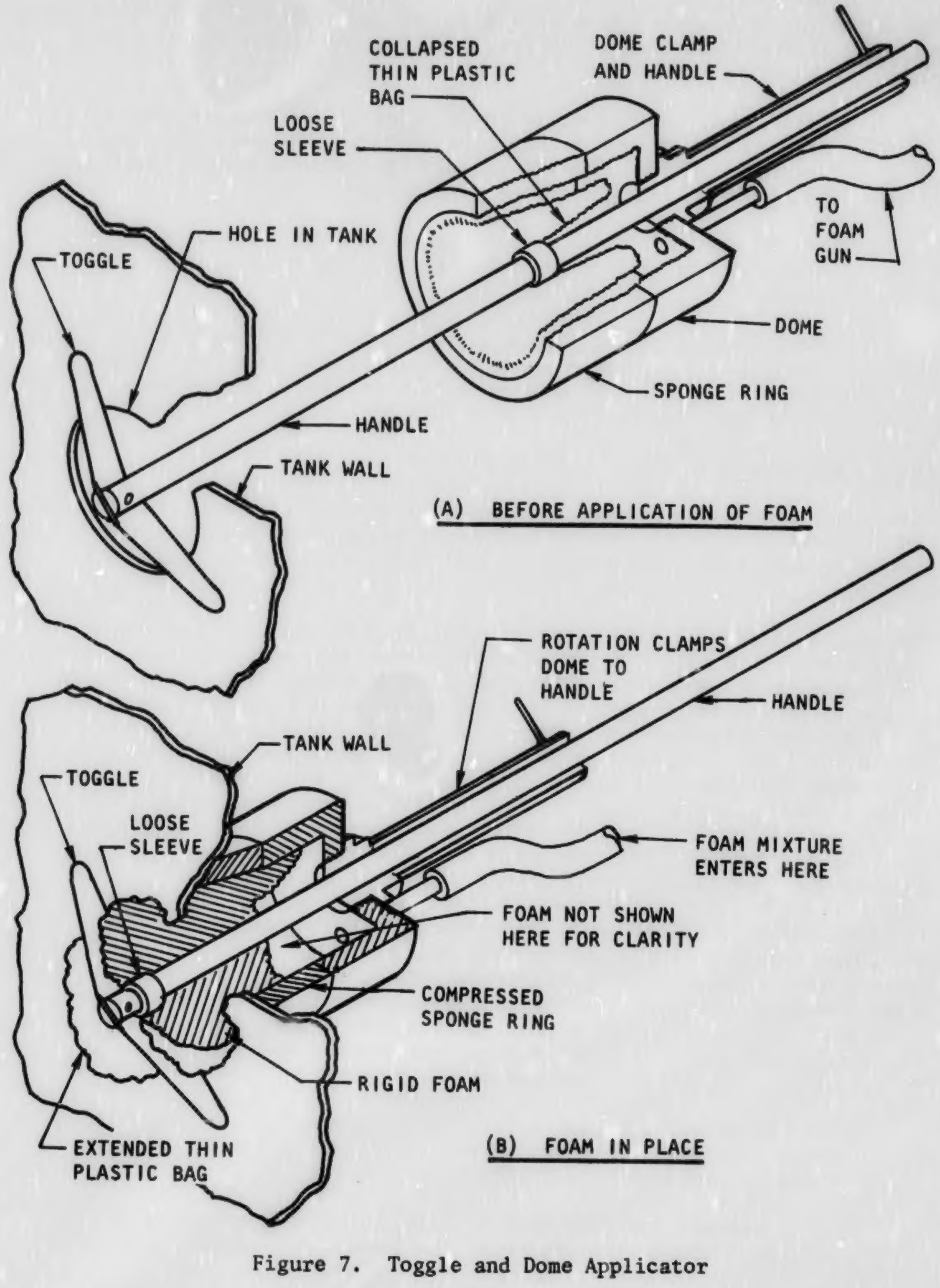

COLLAPSED THIN PLASTIC BAG
DOME CLAMP AND HANDLE
LOOSE SLEEVE
HOLE IN TANK
TOGGLE
TO FOAM GUN
DOME
SPONGE RING
HANDLE
TANK WALL
(A) BEFORE APPLICATION OF FOAM
ROTATION CLAMPS DOME TO HANDLE
HANDLE
TANK WALL
TOGGLE
LOOSE SLEEVE
FOAM MIXTURE ENTERS HERE
FOAM NOT SHOWN HERE FOR CLARITY
COMPRESSED SPONGE RING
RIGID FOAM
EXTENDED THIN PLASTIC BAG
(B) FOAM IN PLACE

Figure 7. Toggle and Dome Applicator

foam sets quite firmly, the buoyant forces are sufficient to break the foam loose from its parent mass. This was avoided in the previous program by carefully timing the moment of foam application after the initial mixing of the ingredients. However, this critical timing requirement is objectionable.

The components of the type of system described above were developed a step at a time. The dome was first tested without a toggle assembly by merely requiring that the operator hold the device in place while the foam was setting. The next step was to build a model having a toggle and means of clamping the dome to the handle. The model depicted in Fig. 7 was constructed and tested.

The next addition to the design was a means of obtaining a mechanical advantage for the operator so that he could more easily compress the sponge rings up against the tank and also to aid in resisting the force caused by the fluid pressure in the tank. These two forces add together, tending to force the operator away from the tank. In addition, this permitted the operator to remain further from the tank while performing the sealing operation without decreasing the maximum tank pressure-hole size combination which can be sealed due to operator strength limitations. The operator pushes the dome forward after having secured the toggle in the hole. When the dome contacts the tank surface, a ratchet is engaged and the operator squeezes the handle repeatedly, each time advancing the dome toward the tank by a small distance until the sponge ring is crushed against the tank sufficiently to stop the major flow of fluid escaping from the tank. The foam gun is then triggered, activating the remainder of the sequence which is the same as for the earlier toggle and dome applicator (shown in Fig. 7).

The drawbacks of this applicator are:

1. Complexity and the associated high cost.
2. Mushrooming of the plastic bag inside the tank is hindered by the presence of the toggle, especially if it is designed sufficiently strong to hold the pressure forces.
3. The force which the operator must exert can be excessive. The dome, especially at the critical time of first contact with the tank wall, will react with a force away from the tank equal to the average pressure multiplied by the cross-sectional area of the dome. This force is necessarily larger than the usual force calculated to stop the liquid flow based on an area equal to the leak since the dome is considerably larger in area than the leak. To this must be added the force required to compress the sponge ring. The operator forces are thus high initially; later, when the mechanical advantage of the ratchet can be used, the operator can probably manage this. However, the design, in order to withstand these forces, becomes too heavy for practical use by one man.

Although the above applicator scheme was not chosen for further development during this program, it may be useful in a mechanized scheme for very large holes where the human strength limitations of a single person are not a factor.

Solid-Rubber Cone Applicator

This solution to the leak-plugging problem is similar to devices which have been used for millennia. Sailors historically have used conically shaped soft-pine cones driven into approximately round holes to stop leaks in ships and in wooden barrels.

A modern version was constructed of fairly soft, casting-type silicone rubber. This cone-shaped plug had an apex angle of 15 degrees and was approximately 25 cm (10 inches) long. It proved to be a very effective plug for round holes of from 2- to 5-cm (3/4- to 1-3/4-inch) diameter.

The rubber is sufficiently soft so that it can be deformed enough (when given a hard thrust into a hole) that its re-expansion inside the tank produces a fairly firm lock. Although very little time was devoted to this leak-plugging technique, the low cost could make such a passive method attractive as a "first aid" measure to serve until more sophisticated equipment could be brought to the scene. (For further discussion, see Section VI, Implementation Plan.)

Foam-Composite Applicators

The most successful type of applicator tip developed during this program is described in this subsection, and further discussed in Section VI, Prototype System, and Appendixes A and B. It was found that an uncured urethane foam (a mixture of the two liquid components) could be forced into the interconnecting cells of a sponge. The foam flows into the cells as it expands and cures, thus forming a new composite material which might be called, for purposes of this report, a foam-reinforced sponge composite or a "foam composite."

Conceptually, the applicator tips consist of a three-dimensional "spear head" cut from a large piece of open-celled sponge (Fig. 8). A tube extends into the sponge along its axis, and has openings through which the urethane foam is introduced into the sponge interior. There is a coating or sleeve on the outside of the sponge cone to prevent or restrict the passage of the leaking chemical into the sponge. The coating or sleeve has a second function, that of permitting expansion of the end of the cone to form a plug inside the leaking container and locking the complete plug into place, as depicted in Fig. 9.

In operation, the applicator tip is pushed into the hole to be plugged. This causes a large, immediate reduction in the flow of liquid. Then a valve is actuated (the timing is completely flexible) to start the flow of urethane foam through the center tube and into the sponge. The sponge swells both inside and outside the hole (typically swelling to

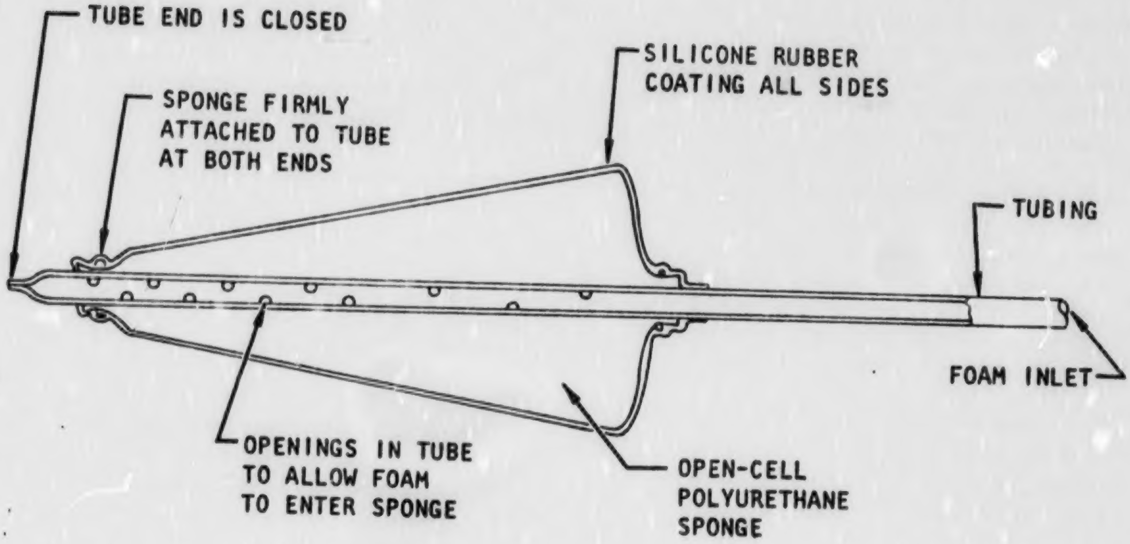

TUBE END IS CLOSED
SPONGE FIRMLY ATTACHED TO TUBE AT BOTH ENDS
SILICONE RUBBER COATING ALL SIDES
TUBING
FOAM INLET
OPENINGS IN TUBE TO ALLOW FOAM TO ENTER SPONGE
OPEN-CELL POLYURETHANE SPONGE

Figure 8. Foam Composite Applicator

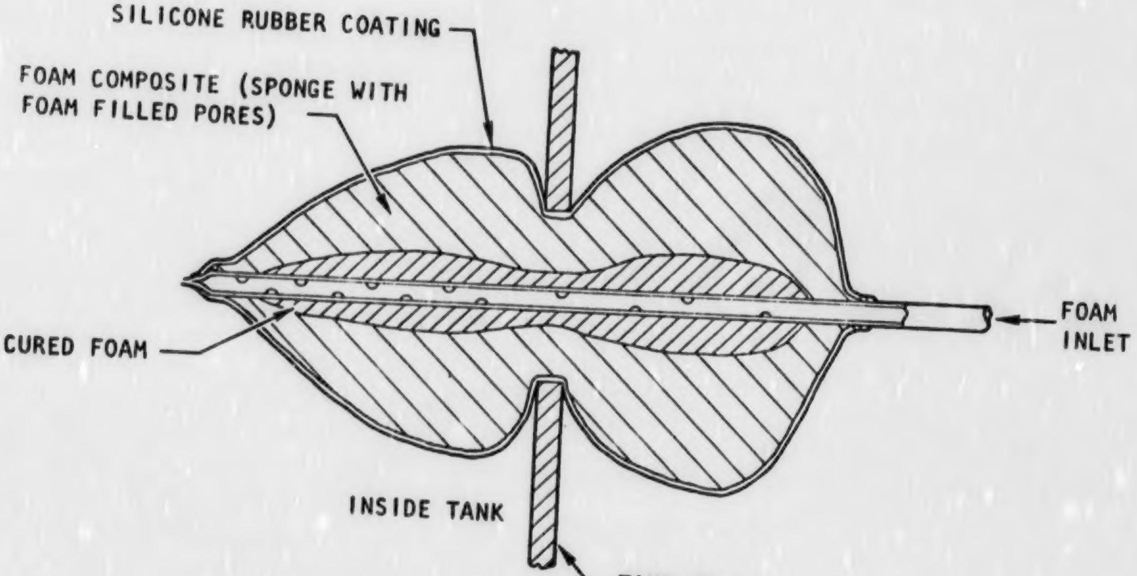

SILICONE RUBBER COATING
FOAM COMPOSITE (SPONGE WITH FOAM FILLED PORES)
CURED FOAM
FOAM INLET
INSIDE TANK
TANK WALL

Figure 9. Foam Composite Applicator After Use to Plug Leak

many times the original volume of the sponge). The probe is held in place while the foam expands and hardens (about 10 to 30 seconds, depending on the characteristics of the foam used). The final result is a hard plug, firmly locked in place, which completely, or very nearly so, stops the leakage of the liquid chemical from the container (Fig. 9).

One of the design considerations is the selection of the covering separating the the expanding foam composite plug from the hazardous chemical. It was found that it is important to prevent the leaking chemical from filling the open cells of the sponge before the foam can be released into the cells. Otherwise, it is difficult for the foam to displace the liquid (the combination of internal hydrostatic pressure and surface forces makes the foam driving pressure to displace the liquid excessively high).

One type of barrier was provided by covering the outer surface of the sponge with single or multiple coatings of a silicone rubber sealant (as shown in Fig. 8). After hardening, the silicone coating prevents the leaking liquid from entering the sponge; yet, when foam is introduced to the interior of the sponge, the trapped air in the foam can escape outward since the silicone rubber coating tends to "open" when it is stretched. This air escape facilitates entry of the foam into the open cells of the sponge.

An alternative to a semiporous coating is either a completely impermeable coating or a loose sleeve, as shown in Fig. 10. Tests with the loose sleeve type of applicator have been very successful, and display an even broader ability to plug leaking containers than is possible with a sponge cone along. Figure 10 also shows a check valve in the foam delivery tube; this feature has been found to be important to prevent the back flow of uncured foam if the applicator is disconnected from the foam supply system

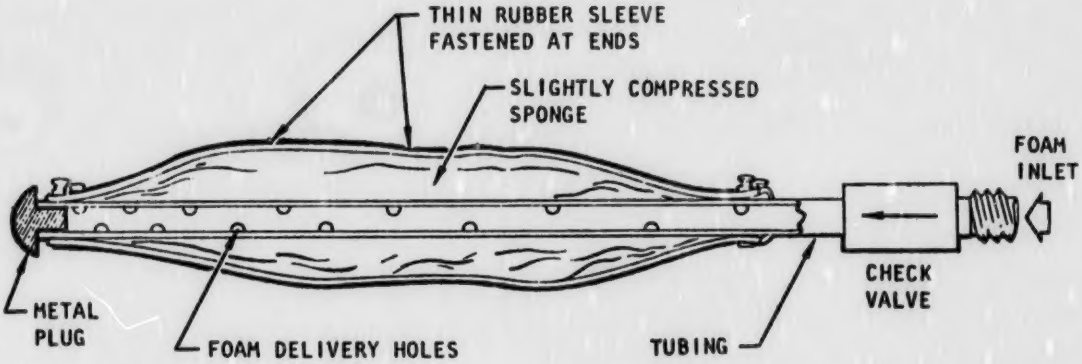


Figure 10. Alternative Foam Composite Applicator

before curing is sufficiently completed (quick-disconnect is not shown). This feature is not necessary in the final design configuration (discussed in Section VI) since disconnecting is not required until the foam has hardened.

Adaptation for Underwater Use. For sealing leaking containers under water, the applicator design was modified slightly to prevent water from entering the applicator and at the same time to allow air to vent outward through a check valve as the foam expands on the inside of the applicator tip. Otherwise, the applicator tip is identical to the one shown in Fig. 10.

Underwater tests identified a difficulty in seeing the applicator as it is inserted into a leak. This is due to the lack of visibility caused by the highly turbulent mixing of the two immiscible liquids right at the point where observation is required. A simple mechanical stop (discussed in Section VI) added to the applicator made it possible for the operator to determine the correct distance by "feel" rather than by sight.

Final Applicator Configuration. The vent and spacer assembly described above were added to the final configuration resulting in the applicator design described in detail in Section VI, plus Appendixes A and B.

Applicator Tip for Narrow Cracks

A new applicator tip and operational technique were developed to sucessfully plug long, narrow holes. The applicator tip is similar to the foam-composite applicator tips described in the previous subsection except that the sponge is basically wedge-shaped, similar to a pyramid, but with a blade edge at the tip rather than a point (see Fig. 19 in Section VI). A plastic bag surrounds the sponge and is sealed to the delivery tube to provide an airtight seal. A vacuum pump is attached to the delivery tube and the air is evacuated, causing the outside air pressure to collapse the sponge into a flat, stiff, triangular shape. The sponge is thus compressed to a thickness of about 1/20 its former thickness, e.g., from a 20-cm (8-inch) thickness to approximately 1 cm (0.4 inch) thick. This compression gives added physical strength to the foam structure, permitting it to withstand the gushing chemical stream that would otherwise tend to fold over a thin, blade-shaped object.

Tests were made with a crack 1.3 cm wide by 13 cm long (1/2 inch wide by 5 inches long). With the air excluded, the applicator was forced into the crack while water [under a 1.8-m (6-feet) head] was flowing out of the hole. The vacuum was then broken, allowing the sponge to expand. Immediately, thereafter, the delivery system was attached and the applicator was filled with foam in the usual way, resulting in a permanent plug.

Although an electric vacuum pump was used for convenience in this experiment, a small hand-operated vacuum pump was later used on a similar applicator with a satisfactory vacuum attained after about 5 minutes of pumping. This time delay probably would be too great for field use.

However, methods for obtaining the required vacuum quickly in the field are possible, e.g., as large-capacity (faster) hand vacuum pump, or prepackaging the deflated applicator tip in a vacuum can. Cracks as thin as 0.3 cm (1/8 inch) might be sealable utilizing smaller versions of the above applicator.

A photograph and description of the final configuration is given in Section VI (Fig. 19).

Alternate Technique for Very Small Holes and Cracks

Another method for sealing very small holes and thin cracks was devised. Preliminary tests show it to be promising for, at least, ferromagnetic tanks.

A patch is first prepared utilizing a semi-flexible backing material (e.g., fiberglass cloth). A two-part epoxy is then mixed, one part of which is heavily loaded (80 percent) with iron fillings. A layer of this rather high-viscosity material is spread on the backing and the patch is pressed firmly against the hole. The epoxy oozes through the crack and at this moment a strong magnetic field is applied by simply pushing a powerful permanent magnet against the patch. The magnetic field immobilizes the epoxy until it has time to harden and it causes the epoxy which has already passed through the crack to draw backward, forming a mushroom shape which provides a mechanical lock after the epoxy has hardened. Once hardening has taken place, the magnet can be removed. The strength of the seal is thus not dependent upon adhesion to a wet surface as in ordinary patching methods using epoxy resins.

Other tests were made using an especially fast-setting metal-loaded epoxy system prepared by the DEVCON Corporation. It sets hard in two minutes.

This technique was not further developed because: (1) the hand-mixed preparation of the epoxy plus hand application of the patch and magnet were somewhat complicated and possibly hazardous for field use, and (2) the potential restriction of application to ferromagnetic tanks may prevent its use in many situations.

FOAM SUPPLY SYSTEM DEVELOPMENT

The foam supply system is needed to deliver urethane foam to the applicator element. This device must provide the functions of storage, transfer, metering, mixing, and delivery of the two Freon-saturated polyurethane components, polyol and isocyanate.

Foam Description

The foam utilized in the final prototype is a commercial urethane foam system and is composed of two parts contained within pressurized cylinders. One cylinder contains a mixture of hydroxyl-terminated polymers (polyols), a cure catalyst (a tin salt), and Freons 11 and 12. The other cylinder contains a mixture of an isocyanate-terminated polymer and a diisocyanate, such as toluene diisocyanate, as well as Freon 12. Volume increase ("foaming") for this system is a function of the volatilization of the fluorocarbon gas, which is the result of the heat generated by the reaction of the isocyanate ingredients with the polyols. This reaction (which is both a chain extension and a crosslinking reaction) produces a matrix of sufficient strength to contain the gas and thus provide a strong closed-cell foam. If the matrix is weak, gas pressure may rupture the cell walls holding the gas and produce an open-cell structure.

To obtain a cured product of the proper mechanical strength, the two-component system must be mixed at the proper stoichiometry and the rate of reaction must be balanced so that volatilization of the gas and generation of the crosslinked structure proceed at such a pace that a closed-cell strong foam results. In commercial applications, this is accomplished by matching the viscosity of the two components over the temperature range from 21 to 32 C (70 to 90 F). It is obvious that temperature will have significant effect on the rate of reaction, the viscosity of the ingredients, the volume expansion, and the foam strength. It is also equally apparent that the present system for plugging leaks should have as broad a temperature capability as possible.

Approximately six manufacturers of commercial urethane foams were contacted and asked for existing foam formulations that might be suitable for the present leak-plugging application. From these potential suppliers, only four viable candidate foam systems (from three different suppliers) were obtained (see Table 1).

Most of the development and prototype testing was done using the Olin 202-C1 system. This is recommended as a baseline for use with the delivered prototypes. The other foam systems were only tested to a limited extent; however, these tests and the manufacturers' specifications indicated that they offered no particular advantages over the Olin 202-C1 system.

Foam Hardware Development

A study of the present, commercially available foam delivery systems was made to determine basic operating principles and the characteristic problem areas. Several preliminary designs were considered based upon the commercial units. It was found, however, that the operating temperature range of commercial foam units was limited to from 24 to 32 C (75 to 90 F). It was desired to extend this range, if possible, to at least 4 to 38 C (40 to 100 F).

Tests with commercial units showed that satisfactory operation could be obtained at 38 C (100 F), but not at 18 C (65 F) and below. Engineering analysis showed that improvement in the system in two basic areas should improve low-temperature operation: (1) the mixture ratio should be more closely controlled, and (2) the mixing intensity should be improved. In addition, physical size and cost reduction along with improvement in

TABLE 1. URETHANE FOAM SYSTEMS EVALUATED

Manufacturer	Product Designation
M. R. Plastics & Coatings 11460 Dorsett Rd. Maryland Heights, MO 63043	Mistafoam 880-S/800-H Rigid Urethane Spray Foam
Midwest Manufacturing Corp. Oak St. at Bluff Rd. Burlington, IA	PP-548 Prepolymer PA-391 Crosslinker
Olin Corp. P.O. Box 847 Benicia Industrial Park Benicia, CA 94510	*Rigid Polyurethane Spray Foam No. 202-C1 (sometimes called Autofroth I chemicals)
	Experimental Rigid Polyurethane Spray Foam No. X-7-1102 ("Fast" Foam)

*Material used in final prototype system

reliability would be essential. These improvements were met by developing rather unique new designs calling for only commercially available, mass-produced components.

The mixture ratio problem was solved by providing a tandem cylinder (two pistons on a common shaft) in which the two foam components are separately stored and are simultaneously expelled at a one-to-one volume ratio using a positive-displacement technique. The driving force is provided by a common carbon dioxide gas cartridge. A full description of the final configuration is given in Section VI.

One of the early breadboard models also provided a method of flushing out the foam chemicals after the system use had been completed so that the system could be reused without extensive cleanup operations. This capability is a part of a normal commercial system. It was found, however, upon studying the system from an overall use viewpoint, that this function was unnecessary since part of the equipment can be considered expendable. Thus, any components which require cleanout have been so constructed that they have become part of the expendable portion of the leak-plugging system. This decision simplified the delivery system considerably and also reduced its cost and the logistics problem of supplying the unit with the now unnecessary cleanout fluid.

A breadboard foam supply device was designed, fabricated, tested, and improved. It was constructed almost entirely of commercially available hardware. The developed foam supply system was used for the prototype leak-plugging system, and is described in detail in Section VI and Appendix A. The device employs a two-compartment tandem cylinder, a puncture pin assembly, two pressure relief valves, four valved quick-disconnect couplings, a mixing chamber, and associated fittings. The two foam components are stored in separate compartments of the tandem cylinder until expelled. The tandem cylinder delivers an accurate fixed-volume ratio of the two components, because a single shaft or rod connects separate pistons in each compartment. The driving force for the expulsion system is provided by carbon dioxide from an ordinary CO_2 gas cartridge. The cartridge is housed in a puncture pin assembly which is attached by gas lines to the tandem cylinder. Prior to using the foam supply device, the cartridge is punctured, releasing carbon dioxide gas through a small regulator to a control valve.

When plugging a leak, the operator pushes the applicator tip into the hole to be plugged and actuates the control valve, allowing the carbon dioxide gas to feed into the pneumatic portions of the tandem cylinder. This drives the pistons in unison, thus expelling the fluids from the cylinder, automatically mixing them, and pushing the mixture into the applicator element. The entire operation requires only a few seconds.

Mixing techniques were studied and several "static" mixers were tested. A unique mixing method was finally conceived and developed which gives good foam production even at low temperatures. The mixing is caused by forcing a quantity of inert gas into the delivery tube along with the two foaming chemicals to produce a highly turbulent two-phase flow. With this gas-mixing technique, the usual static mixer hardware was found to be unnecessary.

This gas-mixing technique was discovered because it was noticed that improved mixing was obtained at relatively high ambient temperatures and that this mixing might be due to increased frothing of the constituents as they entered the mixer. It was thus logical to try the addition of an inert gas at low ambient temperatures to create a similar two-phase flow condition at temperatures where normally insufficient frothing takes place to achieve mixing. This proved successful during a series of tests using this technique. The mixing-aid gas is conveniently supplied from the same pressurant gas supply as is already provided for the tandem cylinder; i.e., a liquid carbon dioxide cartridge. A small orifice automatically limits this mixing gas flowrate to the proper value before it flows through a check valve into the fitting where the two chemical foam constituents come together.

Successful foam delivery tests were made with the entire gas-mixing foam delivery system as hot as 38 C (100 F) and as cold as 7 C (44 F). A final test was made where the delivery system was maintained at 18 C (65 F) prior to use and then suddenly exposed to 0 C (32 F) for a period of 3 minutes. It was then used to plug a hole at this temperature. No leaking fluid was used, however, because it was necessary to perform the experiment in a relatively small cold-box. Good expansion of the applicator tip was obtained and a normal sealing action was predicted, had this been done with an actual leaking tank at 0 C (32 F).

CHEMICAL COMPATIBILITY

Early in the program, the leak-plugging concepts under test involved direct contact between the curing foam and the hazardous chemical that was leaking. Such direct contact presents formidable chemical compatibility problems, because there is much greater danger of chemical attack on uncured foam and foam components than on the cured foam (which, itself, is not resistant to all hazardous chemicals). Subsequent development concepts (and the delivered prototype leak-plugging system) incorporate a barrier between the foam and the leaking chemical (e.g., a plastic or rubber membrane or coating). Such a barrier provides a large improvement in chemical compatibility over direct contact between foam and leaking chemical.

It is anticipated that suitable rubber or plastic membranes can be found for use with most of the chemicals expected to be designated as hazardous substances under 40 CFR, Part 116 (Ref 4). Limited preliminary tests were made to explore the compatibility of some already available membranes.

Table 2 summarizes results of qualitative experiments made to explore the compatibility of the Olin 202-C1 polyurethane foam itself, a rubber membrane (composition unknown) in a commercial bag called a "punch ball," a commercial polyester plastic marketed as "Glad Bags" and an imid-type polyester plastic material marketed as "Brown-in-Bag." These four materials were exposed to six hazardous chemicals representing a broad range of chemical behavior for static exposures of 40 hours (2 minutes for the punch ball rubber) at ambient temperatures. It can be seen that the two plastic membranes had no apparent degradation in any of the chemicals except concentrated sulfuric acid. This chemical resistance was significantly better than the urethane foam and vastly better in organic solvents than the rubber punch ball material. Later tests with neopreme and silicone rubbers displayed marked improvement over the compatibility of the cheap punch ball rubber (which was used in early tests merely because it represented rubber bags of the proper shape and size which were already commercially available.

Table 3 summarizes results from a later series of compatibility tests. In these tests, physical properties (i.e., strength and 200 percent elongation) were tested qualitatively after a 30-minute exposure at ambient temperature to various hazardous chemicals. It was found that certain materials designated "compatible" in the commercial literature were found to be unsuitable for use in this application, mainly because the material did not retain a great degree of its original strength in elongation. The results show that the polyester bag material is by far the superior in compatibility with the six chemicals. However, the advantage of a rubber membrane is that it provides compression of the sponge in the applicator, aiding insertion of the applicator into the leak.

The scope of this program did not permit detailed and extensive compatibility tests. However, it is believed at this time that a combination of a neoprene rubber membrane with a polyester-imid resin bag will be

TABLE 2. STATIC COMPATIBILITY OF LEAK-PLUGGING MATERIALS WITH VARIOUS CHEMICALS

HAZARDOUS CHEMICAL	MATERIAL			
	Polyester (Glad Bag)	Imid Polyester (Brown-in-Bag)	Cured Polyurethane Foam (Olin 202-Cl)	Rubber (Punch Ball)
Methyl Alcohol	no apparent degradation	no apparent degradation	specimen saturated with liquid--possibly some swelling--very spongy	no visible degradation
Benzene	no apparent degradation	no apparent degradation	specimen saturated with liquid--possibly some swelling--very spongy	noticeable swelling
NH_4OH (concentrated)	no apparent degradation	no apparent degradation	some specimen saturation--rather rigid foam structure	small bubble formation
o-Xylene	no apparent degradation	no apparent degradation	specimen saturated with liquid; rather rigid foam structure	noticeable swelling
Sulfuric Acid (concentrated)	incompatible, dissolved almost imme- immediately	incompatible, dissolved almost immediately	incompatible, dissolved forming an orange solution	noticeable fading of blue color to light green, then to brown slowly
Trichloroethylene	no apparent degradation	no apparent degradation	specimen saturated with liquid--possibly some swelling--some rigid foam structure remaining	noticeable swelling
Exposure Time, hr	40	40	40	2 min

TABLE 3. EFFECTS OF HAZARDOUS CHEMICALS ON PHYSICAL PROPERTIES ON LEAK-PLUGGING MATERIALS

Hazardous Chemical	Performance of Leak-Plugging Material*				
	Neoprene Rubber (Medical Type)	Neoprene Rubber (Glove Type)	Polyester ("Glad Bag")	Polyester-Imid ("Brown-In-Bag")	Cured Polyurethane Foam (Olin 202-Cl
Methyl Alcohol	Poor	Satisfactory	Good**	Good**	Poor
Benzene	Poor	Poor	Good**	Good**	Poor
NH_4OH	Good**	Good**	Good**	Good**	Satisfactory
o-Xylene	Poor	Poor	Good**	Good**	Poor
Sulfuric acid (98%)	Poor	Poor	Poor	Poor	Poor
Trichloroethylene	Very Poor	Very Poor	Good**	Good**	Poor

*Retention of Strength and Elongation after 30-Minute Exposure
**Essentially unaffected

sufficiently compatible to allow leak-plugging of virtually all of the important hazardous chemicals.

TEST FACILITY

Two special test facilities were constructed during the program to make expeditious testing possible (Fig. 11). Both had a common feature consisting of a large pipe flange (20-cm (8-inch) pipe for the small facility, and 30-cm (12-inch) pipe for the large facility) placed near the bottom but on the side of the tank and connecting with the inside of the tank. A flat plate and gasket were bolted to the flange, closing off the hole just as in a standard blind flange installation. A hole was cut or punched in the plate, simulating an accidentally made hole in a tank wall. The plates were usually made of 1.3-cm (1/2-inch) thick acrylic sheet, but were occasionally made of 0.3-cm (1/8-inch) thick steel or aluminum. Various plates were made having different hole sizes and shapes. The transparent plates made possible very convenient observation of the expansion taking place inside the tank wall during the test. The removable plates were also convenient for photographing the results and for close inspection of a completed plug after removal from the hole.

This facility enabled tests to be made in a relatively rapid sequence because the plate was removed at the end of a test along with the plug which had been formed in the hole; then a new plate was substituted and the facility was ready for another test. In addition, the large facility had a remotely operated butterfly valve in the pipe section between the tank and the plate. This valve permitted convenient filling of the tank prior to a test and was opened only a few seconds before a test was begun. The valve was closed again before removal of the plate and plug, and the liquid "lost" was pumped back into the tank. This facility also was equipped with a 600-gallon catch tank so that chemicals lost through the leak just prior to plugging could be caught and reused, thus saving a disposal and procurement cost, preventing an environmental problem, avoiding materials delivery delay, and permitting an estimate to be made of the quantity spilled before plugging was completed.

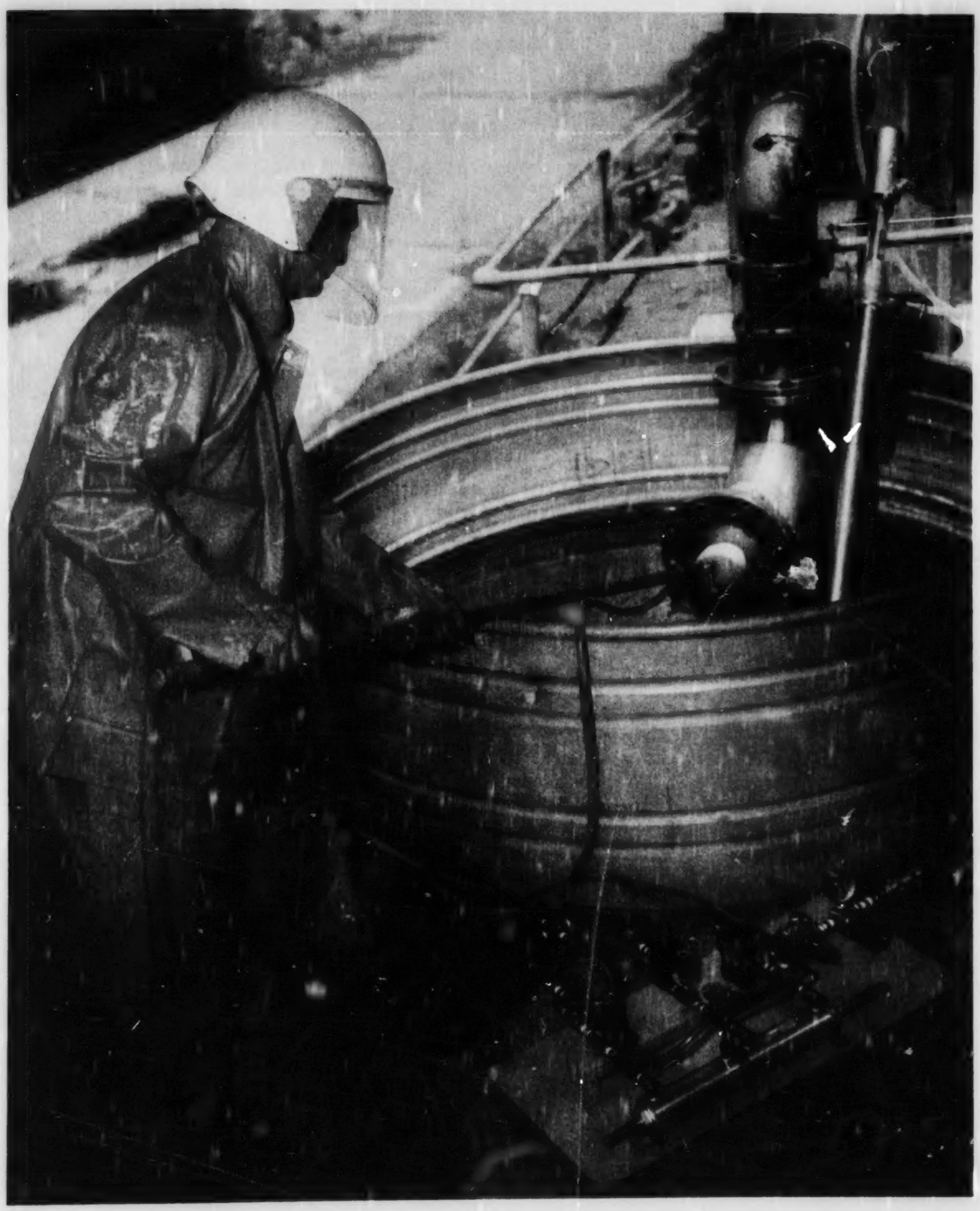


Figure 11. Test Facility in Use

SECTION VI

PROTOTYPE SYSTEM

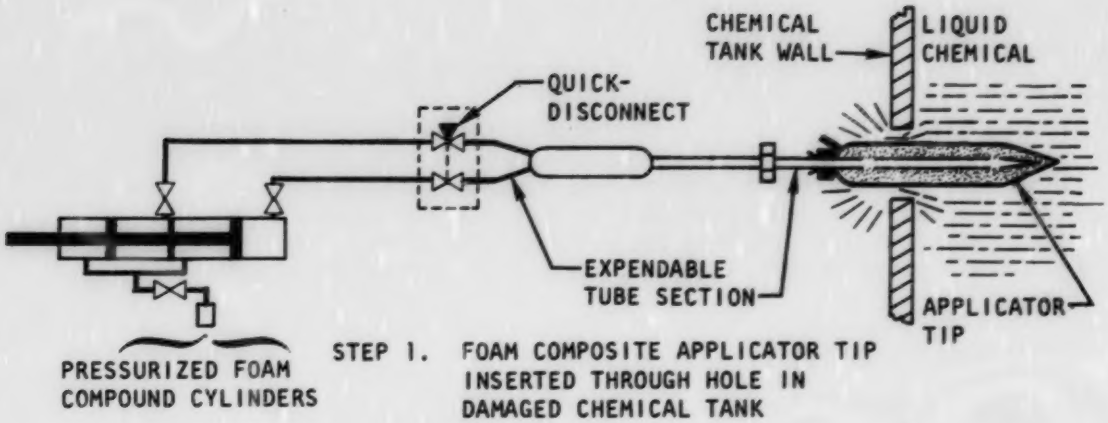
This section describes the prototype leak-plugging system which was developed during and delivered at the end of the program. Appendix A contains detail design drawings and a parts list for the delivered prototype. Appendix B gives detailed instructions for refilling the foam delivery system.

SYSTEM DESCRIPTION

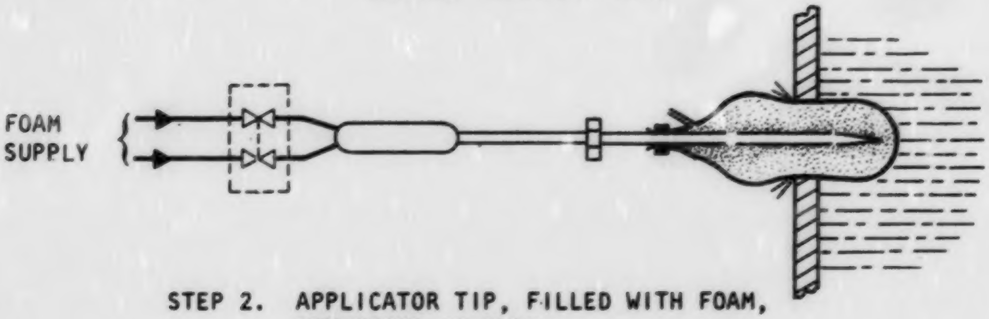
The basic principle of the delivered prototype leak-plugging system is illustrated in Fig. 12. The system consists of a foam supply device (pressurized cylinders plus control and mixing elements shown on the left of Fig. 12), and an applicator (shown on the right side of Fig. 12) which places the foam in the hole to be plugged in an effective way to seal the hole. The applicator has a handle with an actuating device on one end and an applicator tip on the other end.

The tip is thrust into the hole to be plugged and the delivery system is activated by the operator. This causes two urethane foam components to be released from their pressurized containers, automatically mixed together as they flow, and forced into the applicator tip while it is being held in the hole (partly inside the container and partly outside the container). Expansion of the foam causes the applicator tip to expand both inside and outside the tank wall simultaneously, filling the hole and stopping the leak. About 2 minutes after the start of this expansion, the foam has become hard enough to permit removal of the handle and the delivery tube; the plug is then self-supporting. Ninety percent of full strength is reached after another 5 to 10 minutes, depending upon the temperature; some additional strength is gained during the subsequent hour or so.

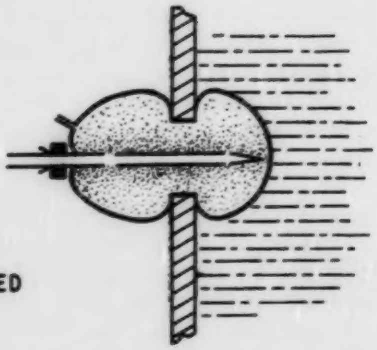
The delivery system then can be disconnected, recharged with foam components, and attached to a new applicator (in the field), rendering the system ready for a repeat plugging operation, if required. This repeated use can continue over many cycles. However, after the period of emergency use in one incident, the leak plugging system should be carefully cleaned and refilled, to ensure reliability during its next emergency use. This servicing might be set up on an exchange basis with the manufacturer, returning the fired unit to the factory for cleaning and refilling in exchange for a previously serviced unit. It should be possible to store a factory-serviced system for periods of a year to possibly several years (storage life tests will be needed to establish safe periods), depending upon precautionary details called for and carried out in the construction, design, and storage of the delivery system.


CHEMICAL TANK WALL
LIQUID CHEMICAL
QUICK-DISCONNECT
EXPENDABLE TUBE SECTION
APPLICATOR TIP
PRESSURIZED FOAM COMPOUND CYLINDERS

STEP 1. FOAM COMPOSITE APPLICATOR TIP INSERTED THROUGH HOLE IN DAMAGED CHEMICAL TANK


FOAM SUPPLY

STEP 2. APPLICATOR TIP, FILLED WITH FOAM, EXPANDING IN HOLE



STEP 3. FULLY EXPANDED AND CURED COMPOSITE FOAM PLUG SECURELY IN HOLE

Figure 12. Basic Concept of Prototype Leak-Plugging System

The urethane foam system used as a baseline is Olin No. 202-C1. Other foam systems may give equivalent performance, but should be tested before selection.

Rigid polyurethane foams are formed by the reaction of certain isocyanate compounds with hydroxyl-bearing polyols which, when mixed together in the presence of a catalyst and other additives, chemically react to form multi-branced polymer chains.

In the process of forming the foam, the two basic components are pressurized in separate cylinders with an extremely low boiling fluorocarbon and are fed through a static mixing chamber, in a controlled ratio, and then expelled. The sudden decrease in pressure during expulsion at the mixing chamber causes the low boiling fluorocarbon to volatilize, thus creating a froth material very similar to aerosol shaving creams. This material further expands as the heat generated from the chemical reaction of the isocyanate and polyol causes the continued expansion of the fluorocarbon gas until finally, in a relatively short period of time, the polymer has obtained sufficient strength to withstand the pressures of the expanding gas and the material completes its rise and starts the curing process. The final product is a homogeneous cellular material comprised of many tiny closed cells, each containing some of the fluorocarbon gases.

PNEUMATICALLY OPERATED DELIVERY SYSTEM

Figures 13 and 14 show the pneumatically actuated delivery system. A complete set of design drawings and a components parts list are given in Appendix A. The part numbers in the photos, the drawings, and the parts list are all consistent.

The largest component is the tandem cylinder (No. 40 in Fig. 14), which contains polyol (Chemical B) in the right end and isocyanate (Chemical A) in the left end. On the other side of both pistons is a space into which the carbon dioxide pressurant gas is conducted. This gas comes from a small carbon dioxide cartridge (2), through a puncture pin valve (1), through a pressure regulating valve and gage (3), through a normally closed pneumatically operated valve (6), and into the two tandem cylinders.

The tandem cylinders are initially filled with chemicals through two quick disconnects (35 and 36), causing the pistons to rest in their left-most position with maximum protrusion of the external shaft to which the two pistons are connected. When the operator causes valve 6 to open, the carbon dioxide gas forces the two tandem pistons to the right, expelling the two chemicals simultaneously through pressure relief valves (33 and 34) that are set at 120 psi, then through quick disconnects (37, 38, and 104), and into the mixing cross (101) where they are joined by a flow of mixing gas which aids in delivering the mixed chemicals down the flexible delivery tube (120) and into the applicator tip. (Parts 101, 104, and 120 are shown in Appendix A.)

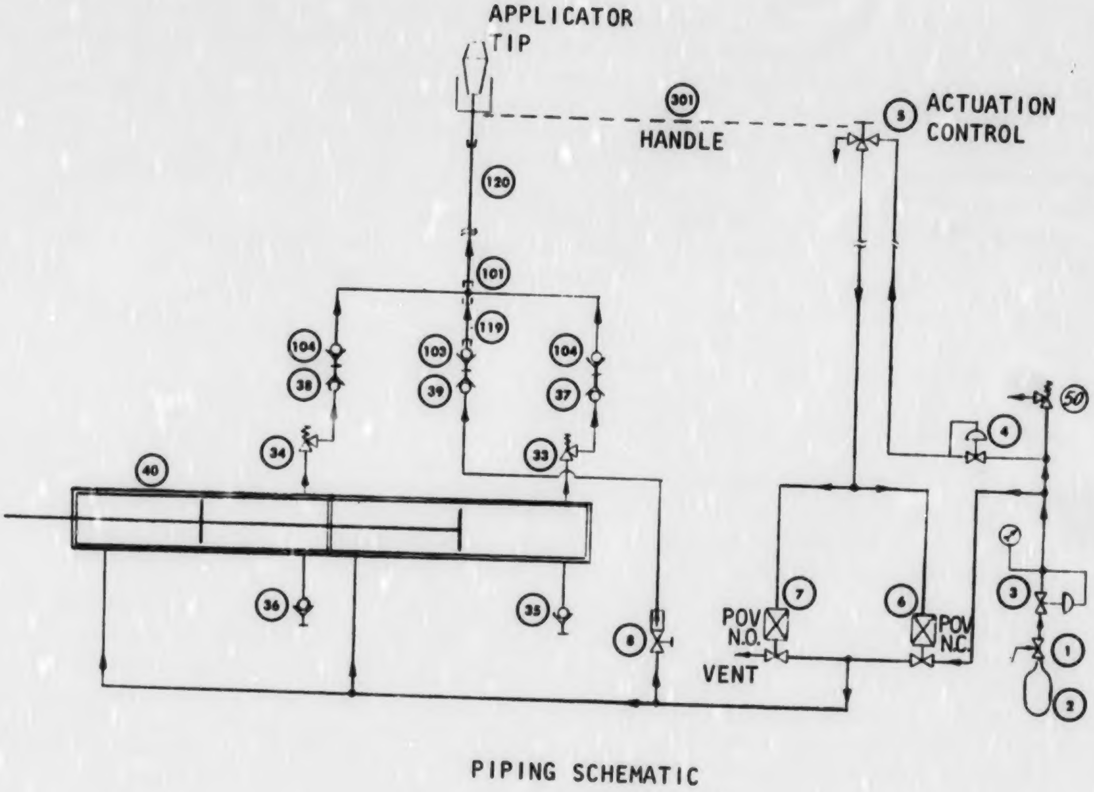

APPLICATOR TIP
301
HANDLE
5
ACTUATION CONTROL
120
101
119
104
103
104
38
39
37
50
34
33
4
40
3
36
35
7
6
8
POV N.O.
POV N.C.
VENT
1
2
PIPING SCHEMATIC

Figure 13. Schematic Diagram of Pneumatically Operated Prototype Foam Delivery System

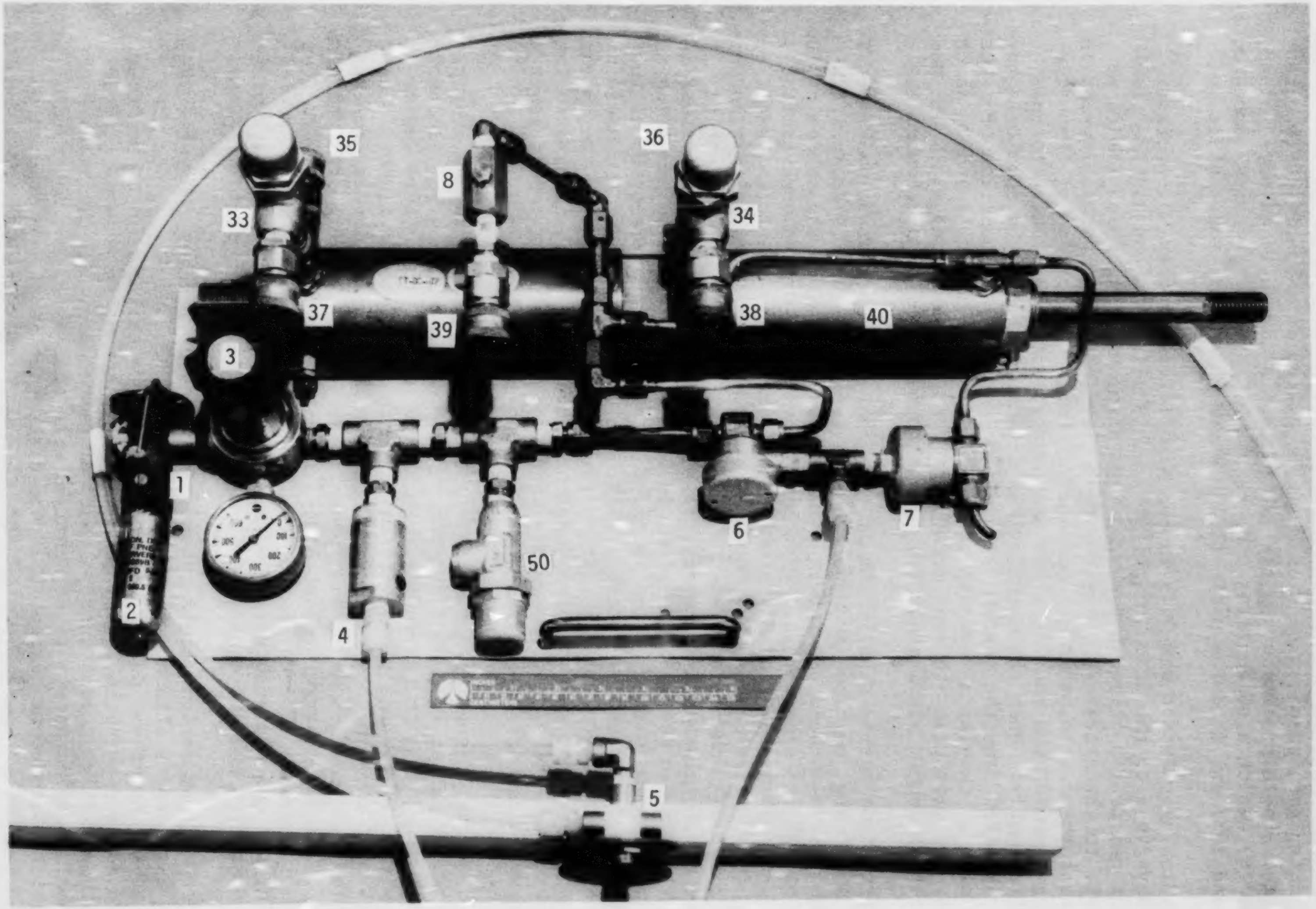

35
36
8
33
34
37
39
38
40
3
1
6
7
2
50
4
5

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Figure 14. Pneumatically Operated Prototype Foam Delivery System

The mixing gas, also carbon dioxide, is obtained at a specific flowrate from the single pressurant supply (2) through a carefully adjusted bleed valve (8), which also contains a check valve, through the quick disconnects (39 and 103) and into the cross (101), where the mixing takes place.

Actuation of valves 6 and 7 is caused simultaneously when the operator turns valve 5 to the actuate position. This allows carbon dioxide pressurant gas to flow through pressure-regulating valve 4, which is set at 70 psi, to the actuators on valves 6 and 7. Valve 7 is normally open, in contrast to valve 6, which is normally closed. Application of the actuation gas causes the vent to close and the pressurant gas valve to open simultaneously. When the operator has decided that all the chemicals have been expelled from the tandem cylinder, he reverses the position of actuating valve 5, causing a reversal of the positions of valves 6 and 7, which allows the pressurant to vent from the tandem cylinders and shuts off the pressurant supply simultaneously, thus stopping the flow of chemicals.

The actuation period (the length of time that the operator holds valves 5 in the actuate position) is usually about 10 seconds but is not critical as long as it is held open about 5 seconds or more after the tandem piston has reached its extreme, full-expulsion, position. Once the pressurant has been vented, the tandem pistons usually return to the left a small distance due to the pressure exerted by the small amount of chemicals not expelled during actuation. (This is of no consequence.) The actuation stroke of the pistons is automatically limited by the mechanical stops in the cylinder. A partial expulsion can be easily obtained by providing a mechanical stop for the piston in the form of a short piece of metal tubing around the protruding shaft. (This feature has not been included in the delivered design.) Again, it is important to realize that the operator is not required to make careful judgments about the length of time to leave the actuation valve open; he merely needs to leave it open for at least a few (say 5) seconds beyond the end of piston movement.

Once the flow of chemicals from the tandem cylinders has stopped, the pressure relief valves (33 and 34) automatically close and then act as check valves, preventing the expanding foam in the mixing cross (101) and delivery tube (120) from flowing backwards into the tandem cylinder. The check valve incorporated into mixing gas bleed valve (8) serves the same function for the pressurant gas system. The flexible tubing (119) between parts 103 and 101 serves to catch any expanding foam coming backward from the mixing cross. The applicator tip and all components down to and including the quick disconnects (103 and 104) are expendable for each plugging operation and are consequently allowed to fill with expanding foam.

However, system design should provide that no foam reaches the permanent quick disconnects attached to these (parts 37, 38, and 39), since they are part of the permanent delivery system and may be called upon to be reused before a major servicing. Any foam which has set up in them will render them temporarily useless until cleaned or overhauled. On the other hand, the neat foam components (i.e., unmixed with the other) are not harmful to the quick disconnects, except that the disconnects that are exposed to isocyanate (36 and 38) for 3 hours or longer will become more and more difficult to operate because of the reaction between this material and the moisture in air. Should the delivery system be required to be actively used for a time period exceeding 3 hours, then a "first-aid" type of maintenance should be performed consisting of flushing these two components with a solvent to remove excess (and exposed) isocyanate.

To reuse the delivery system, the tandem cylinders are refilled as described in Appendix B; a fresh carbon dioxide cartridge (2) is substituted for the expended one. The old mixing and delivery system (101, 103, and 104) is removed and a fresh applicator assembly is attached; first, the applicator tip is attached to the handle and then the quick disconnects are attached to the delivery system. The system is then ready to perform another plugging operation.

A pressure relief valve (50) is provided for safety purposes. Should the pressurant gas exceed 250 psig, then this valve will automatically relieve the pressure by venting the excess. This ensures that no damage will result if the main regulator valve (3) should fail or if the operator should set the pressure at too high a level.

MECHANICALLY OPERATED DELIVERY SYSTEM

A second prototype system was delivered (Fig. 15) which includes a foam delivery system very similar to the pneumatically operated delivery system just described. The only significant differences are in the tandem cylinder size and in the method for activating the flow of foam.

A mechanical actuating means is provided in the system shown in Fig. 15 by substituting a control cable for the pneumatic tubing and the pneumatic actuation components used in the other prototype (Fig. 14). To achieve actuation, the operator moves a lever at the handle end of the control cable (Fig. 15). This pulls down a hinged bracket against the button of a three-way palm button valve. (For design details, see note 8 of the component specification list in Appendix A.) This three-way valve serves the same function as the two pneumatically operated valves (6 and 7) described in the previous section, i.e., it closes off a vent port and opens a passage to allow the pressurant gas to pass from the pressure regulator into the tandem piston, causing it to actuate. Part of this gas is also conducted through the mixing gas bleed valve (8) into the mixing cross (101).

The mechanical system requires fewer commercially available components than the pneumatically operated system, but requires a greater number of specially fabricated brackets and levers. The costs of the two prototype systems are not significantly different. The mechanical system has a modest weight advantage relative to the pneumatic system. Systems with fewer components usually have increased reliability; however, pneumatic systems are usually inherently more reliable than their mechanical equivalent. The overall reliability of the two systems should be expected to be approximately equivalent. However, in development testing of the two prototype

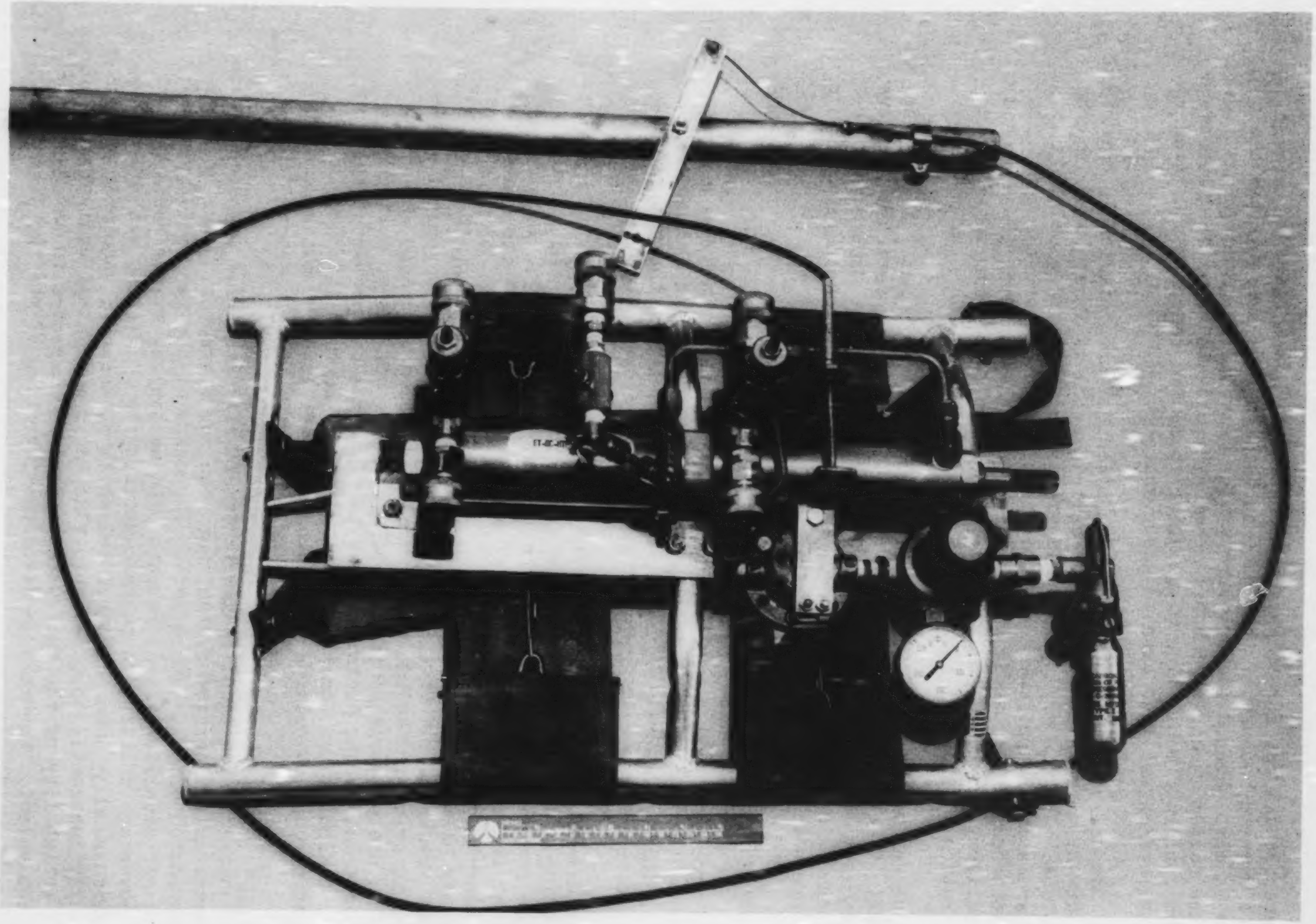

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Figure 15. Mechanically Operated Prototype Foam Delivery System

systems, it was found that the pneumatic actuation system was slightly more reliable.

Both the pneumatically and mechanically actuated leak-plugging systems are practical and there is not a large difference, overall, between them. However, the pneumatic actuating system is recommended since the increased reliability is considered to be an essential advantage in a leak-plugging system which will be used or tested relatively infrequently and which will be used in an inherently dangerous environment where equipment reliability has a high premium.

APPLICATOR

The prototype applicator is shown in Fig. 16; detail drawings and a parts list are given in Appendix A. The operating principle of the foam composite applicator chosen for the prototype was also discussed in Section V and further illustrated there in Fig. 8 through 10. The main structural member of the applicator is the metal delivery tube running in the center between the long, flexible delivery tube on the right and the applicator tip on the left. The U-shaped, dark-colored piping in the center is the spacer subassembly. It is adjustable; movement can be obtained forward and back by sliding it up and down the metal delivery tube after loosening the hose clamp surrounding the short piece of split tubing at its center. The function of the spacer is to give the operator an automatic stop against the side of the tank when the applicator tip is inserted into the leak, thus eliminating operator judgment and skill in the in-and-out positioning of the applicator during a leak-plugging operation.

In Fig. 16, the transparent vent tube can be seen protruding from the right end of the applicator tip. This tube allows air inside the tip to escape as displaced by the foam entering at the center, and reduces the back pressure which would otherwise be generated by the trapped air.

After the tip has been inserted into a hole up to the end of the spacer prongs, the operator actuates the delivery system. This causes mixed chemicals and carbon dioxide mixing gas to flow rapidly through the flexible hose and metal delivery tube, and then into the applicator tip through holes in the metal delivery tube. Most of these exit holes are at the very tip of the applicator, while only two are near the vent tube end (details are given in the Appendix A drawings). The positioning of the exit holes allows foam chemicals to enter the applicator tip through its length. Figure 17 shows an expanded applicator tip after plugging a hole approximately 6.1 cm (2-1/2 inches) across under a water head of 3 meters (10 feet). The jagged hole was cut in a clear plastic plate for ease in viewing. Figure 18 shows a similar expanded applicator tip, sectioned for viewing.

After the foam is set, the handle can be easily separated from the applicator tip by loosening the thumb screw at the tip of the handle. The long applicator hose can be removed by simply cutting the foam-filled hose with a pair of diagonal cutters or a knife.

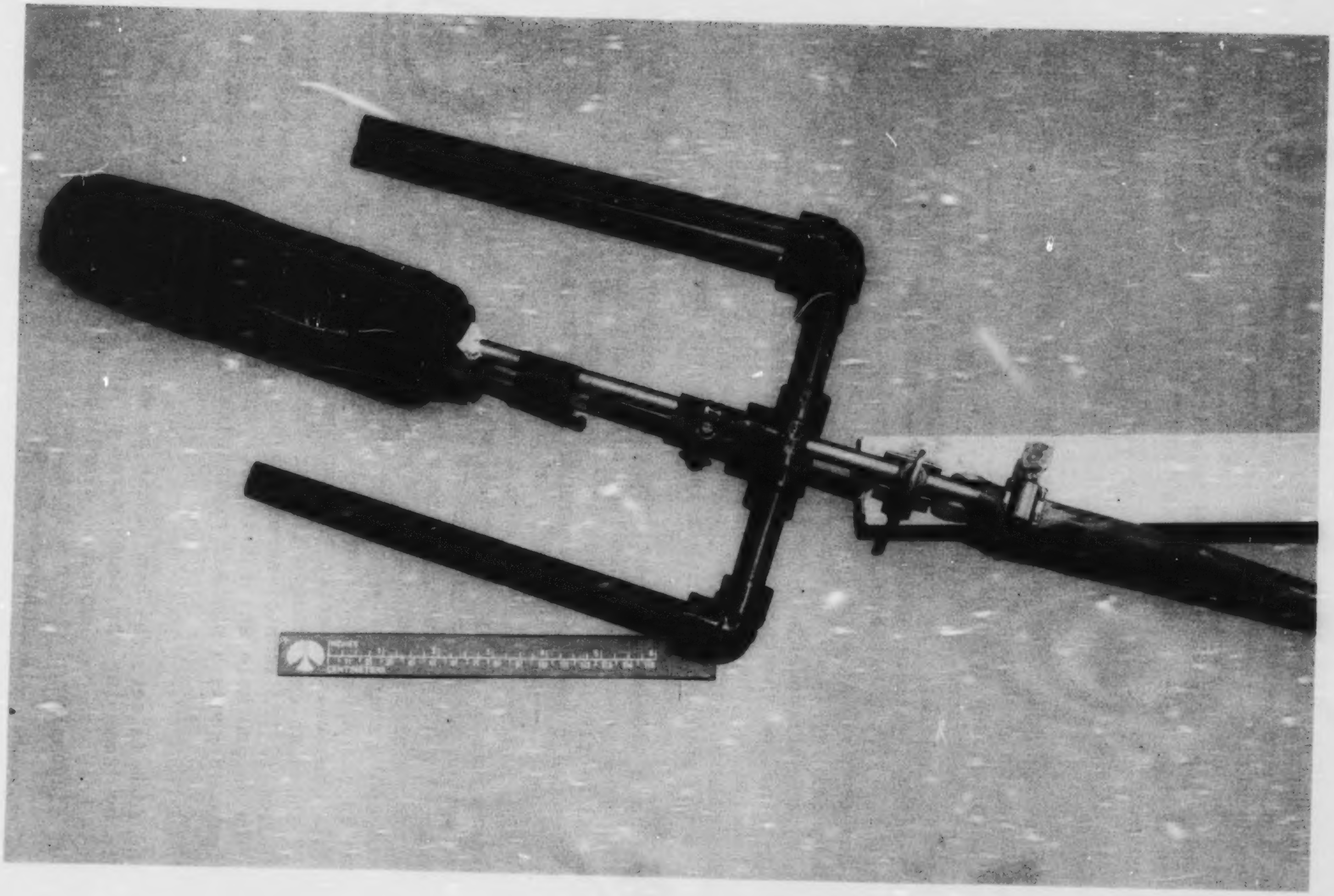

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Figure 16. Prototype Applicator

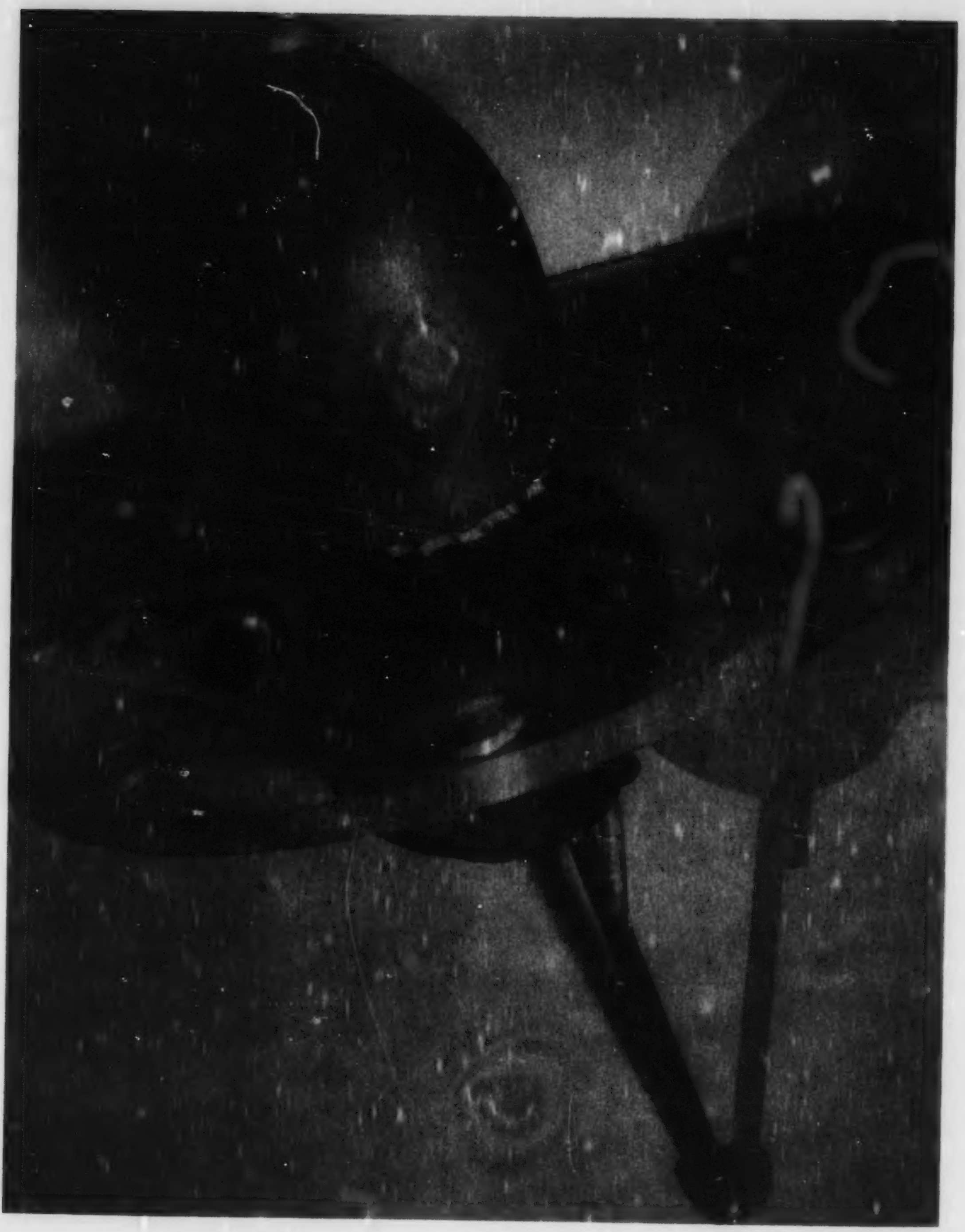

Figure 17. Prototype Applicator After Plugging

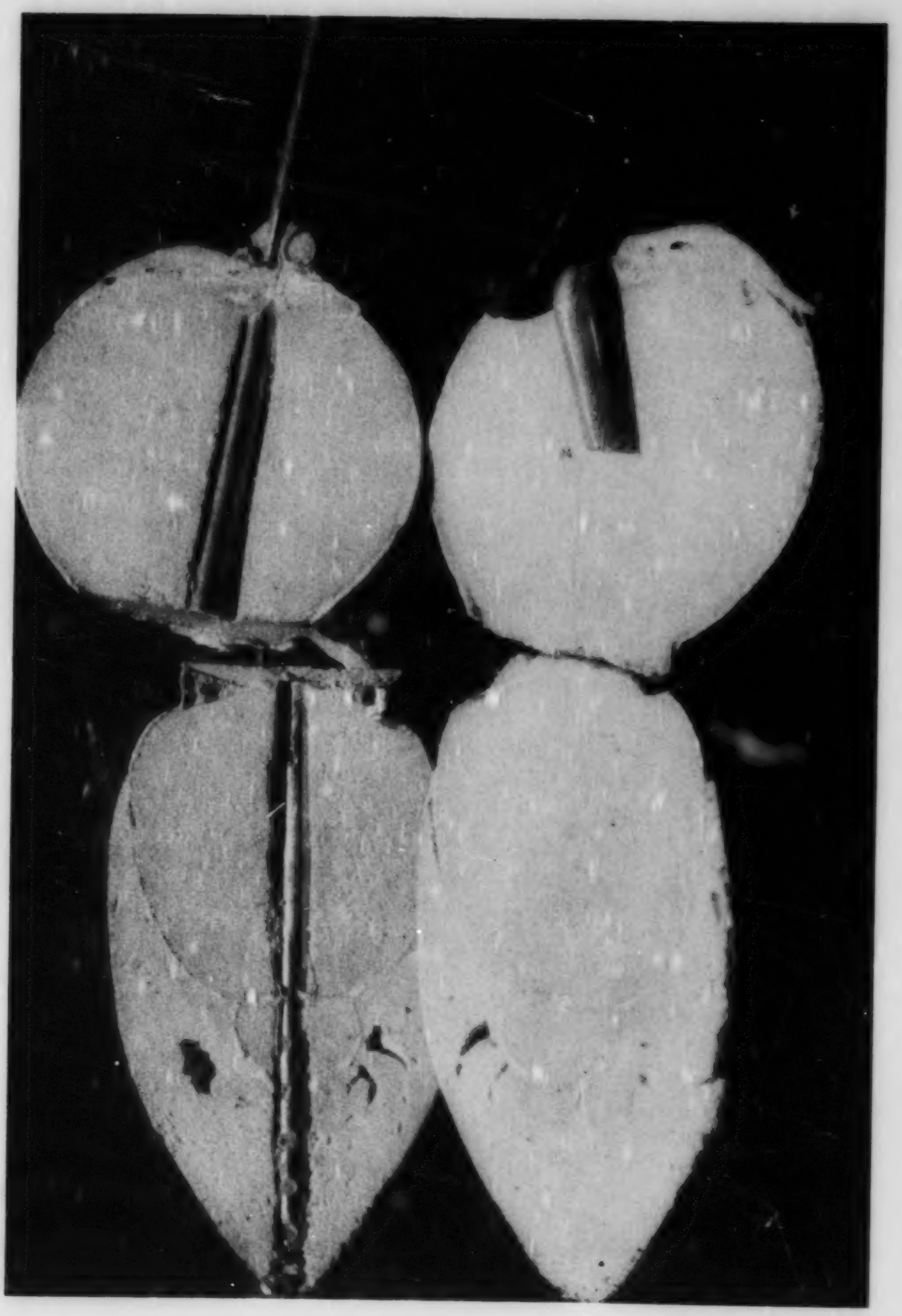

Figure 18. Sectioned Prototype Applicator After Plugging

The present prototype design requires that the given mixing assembly be used with a given tandem cylinder size, i.e., it is not interchangeable between large and small prototypes (see note 2 of the parts list). However, the tips are easily detached, and any tip can be used with any mixing assembly.

Applicator for Cracks

Some development also was done on a special version of the foam composite applicator for use in plugging long narrow holes (e.g., cracks). Figure 19 shows a prototype of the special applicator tip. This particular tip is sized to plug cracks wider than approximately 1.3 cm (1/2 inch) and up to about 15 cm (6 inches) long. The use of several such tips side by side will permit plugging of very long cracks.

The applicator tip, although shown to be about 20 cm (8 inches) thick in Fig. 19, is compressed to only about 1 cm (0.4 inch) thick by evacuating the space within the transparent plastic bag. The outside air pressure collapses the central sponge into a flat, spear-head-like shape. The metal delivery tube runs all the way to the tip and is flattened at the end to permit easy entry, along with the sponge, into the crack. Once the tip is inside a hole, the operator breaks the vacuum by connecting the quick disconnect on the upstream end of the rubber hose to the mixing assembly (shown at X in the upper middle of Fig. 19), and thus connects it to the foam delivery system. The quick-disconnect contains a spring-loaded check valve that opens when the quick disconnect is connected. This action allows the flow of foam chemicals into the rubber delivery tube and on into the applicator tip. The stopper is removed from the long vent tube to permit the mixing gas to escape to the atmosphere, relieving the back pressure inside the applicator caused by the entering foam chemicals. In its present state of development, this applicator is more difficult to use in a leak-sealing operation than the normal applicator. Further development is needed to simplify its use.

METHODS OF USE

Figure 20 shows the complete mechanically actuated prototype leak-plugging system with the foam delivery system mounted on a standard backpack frame, and with the operator holding the applicator tip and handle attached to the delivery system ready for use. Although the mechanical system is shown in Fig. 20, a simple substitution allows mounting the pneumatically actuated system in an identical way.

It has been found from experience that a convenient alternate method is to carry the system like a suitcase in one hand to the spill site and then to lay it on the ground next to the operator at the site of the leak. The backpack configuration can be used in this way, using one of the side supports of the rack as a handle. Figure 14 shows the pneumatically actuated prototype mounted on a flat plate with a handle, in lieu of the rack. Wearing the backpack will be an advantage where the operator must use both hands to climb a ladder or similar function, while carrying the applicator

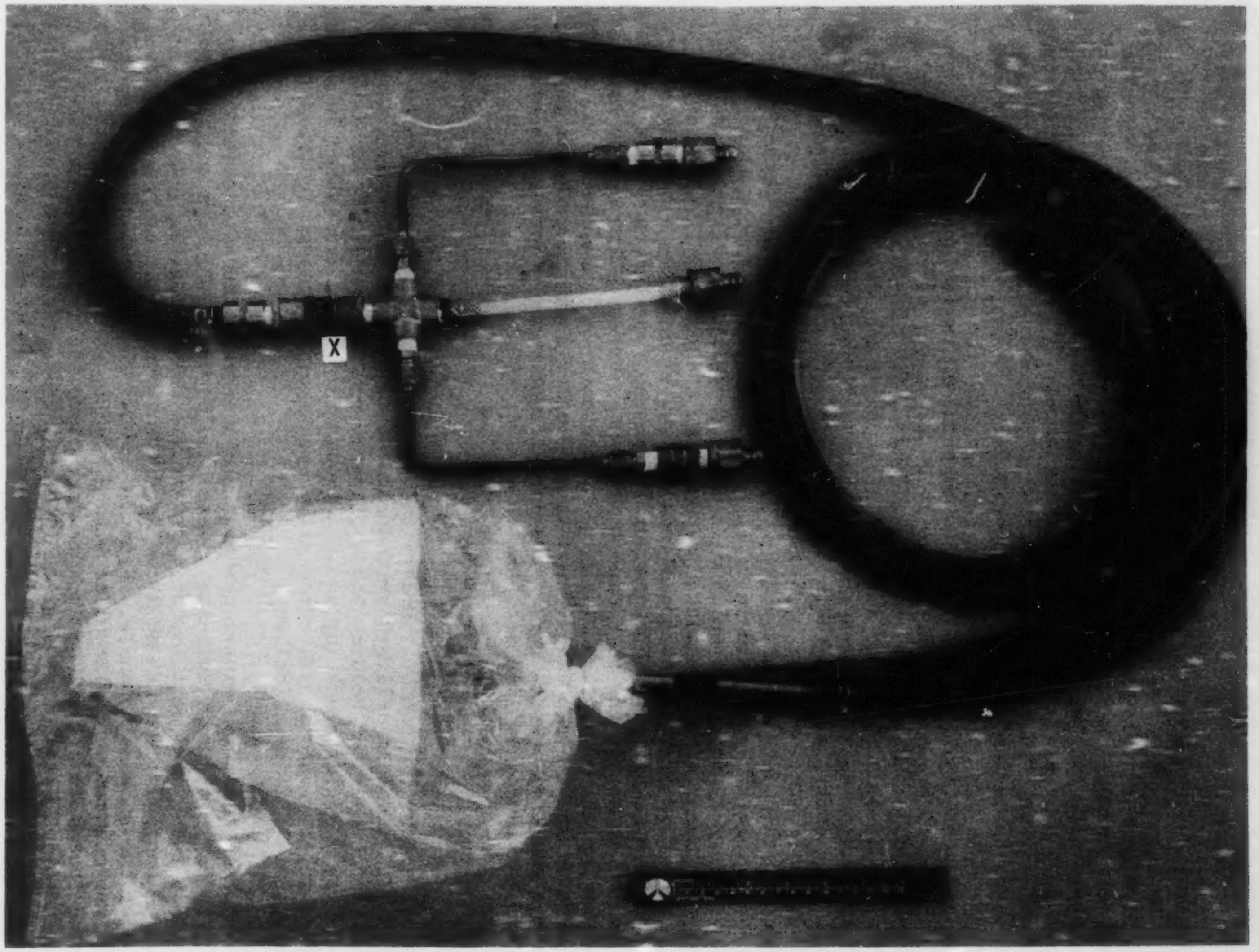

Figure 19. Prototype Applicator for Cracks

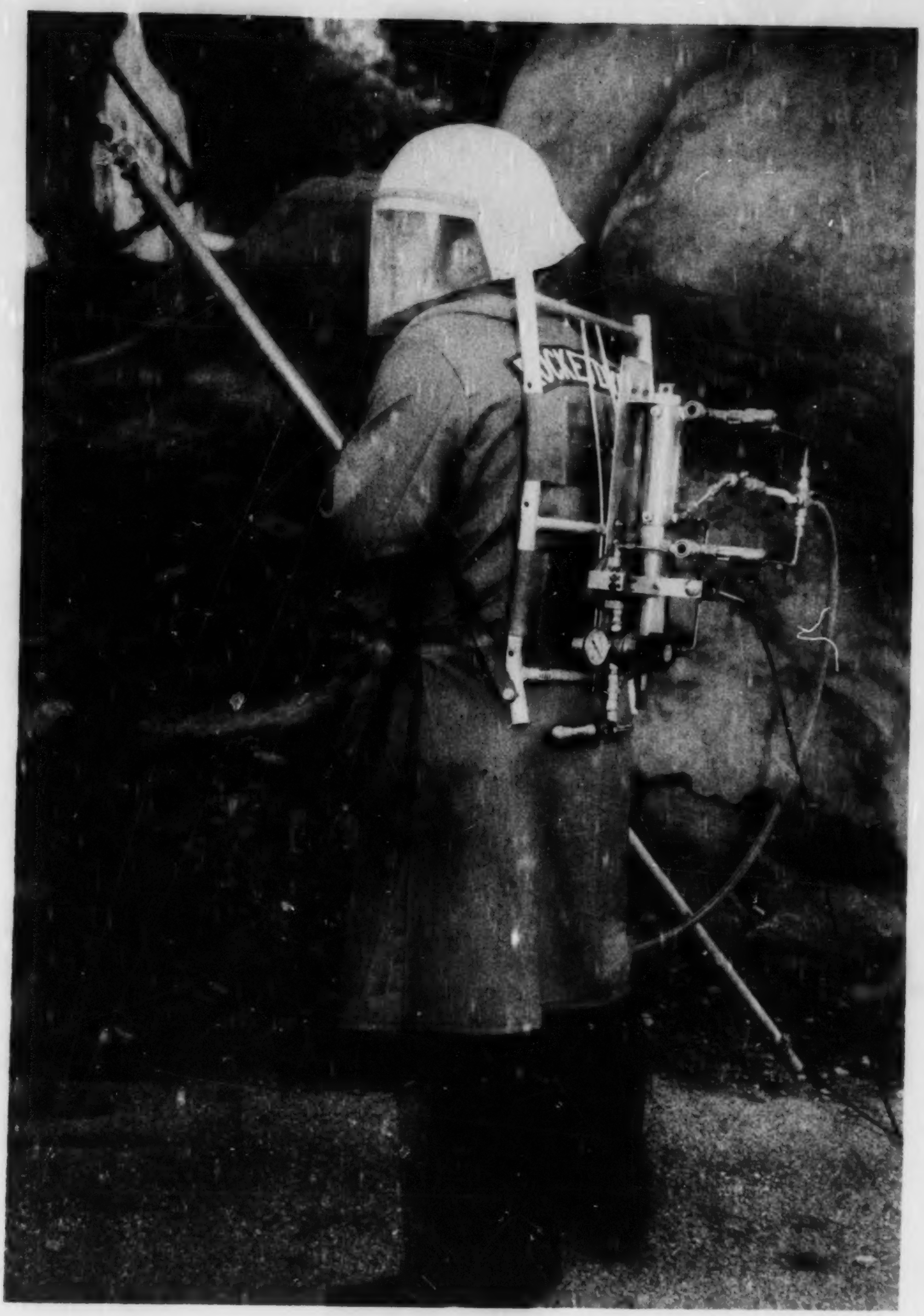

Figure 20. Back-Mounted Leak-Plugging System Ready for Use

handle at the same time. On the other hand, if crowded quarters must be entered, the rack may snag on protruding structural members, in which case, carrying the delivery system by hand at the operator's side may be preferable. Mounting the delivery system on the chest of the operator instead of on his back also might be advantageous in extremely restricted areas.

Operation

The use of the leak-plugging system is illustrated in Fig. 21 through 26 (which show photographs of a leak-plugging sequence from the development testing), and is discussed in this subsection.

The component subassemblies are first removed from their storage place in the emergency vehicle. Protective clothing, if required, is put on except for the helmet. A carbon dioxide cartridge (2) is screwed into the place provided for it. The lanyard is pulled to puncture the CO_2 cartridge. The pressure is checked on the pressure gage to see if it is at 250 psig. If not, the regulator knob is turned until the pressure is 250 psig.

Once the lanyard has been pulled to puncture the carbon dioxide supply cylinder, the lever attached to the lanyard should be placed back in its resting position prior to activation to ensure that the piston rod, during later actuation, will not strike against the lever and break the puncture pin assembly housing. Should this happen, the assembly will have to be replaced. A simple design change can be made in subsequent models to eliminate the need for this precaution.

An applicator tip is selected and attached to the handle. The quick disconnects on the mixer subassembly are plugged into their mates on the delivery system. The unit is placed on the operator's back and the helmet is donned; the handle is then picked up (Fig. 20). The operator then walks up to the leak (one from the development test facility shown in Fig. 21), approaches it from the side and thrusts the end of the applicator into the hole until the ends of the spacer contact the tank surrounding the hole (Fig. 22). The axis of the applicator tip need not be at a right angle to the tank surface surrounding the hole. The operator immediately turns the valve at the end of the handle, causing the delivery system to fill the applicator tip with the foam-producing mixture. The foam begins to expand the applicator tip rapidly, both inside and outside the tank wall. Typically, most of the leak is stopped within about 10 seconds (Fig. 23). The foam expansion is complete in about 30 seconds, with maximum tank sealing (Fig. 24 and 25). An applicator tip, expanded on both sides of the tank wall, forms a tough, rigid plug that is locked in place (Fig. 26).

During foam delivery and for about 2 minutes afterward, the position of the probe should be held as steady as possible against the pressure of the outrushing tank fluid. Once the plug is hard, the handle is unclamped and laid aside. A knife or pair of diagonal cutters is then used to cut the long delivery hose. The operator picks up the handle, moves back a safe

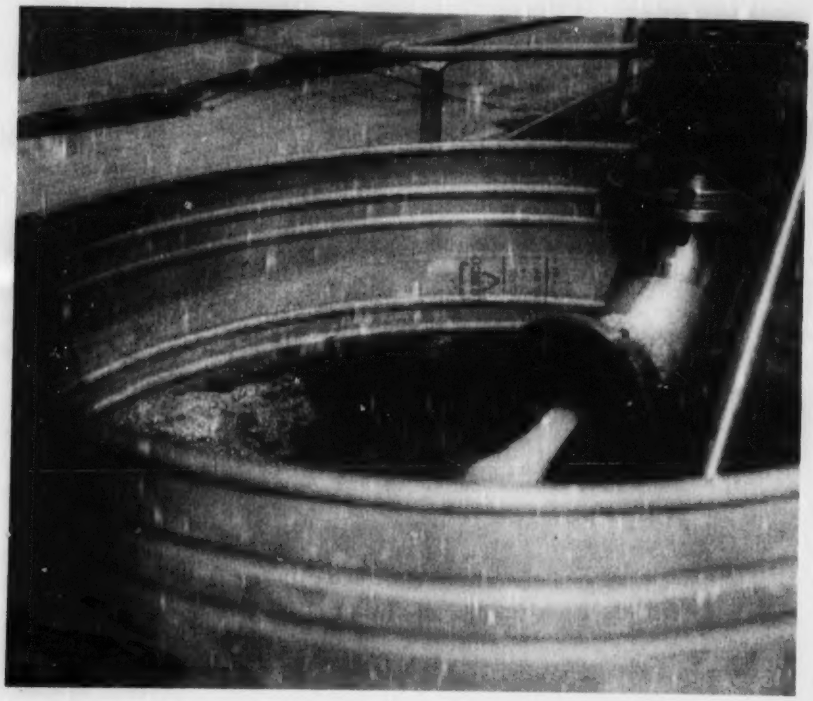

Figure 21. Gushing Liquid Leak in Test Facility

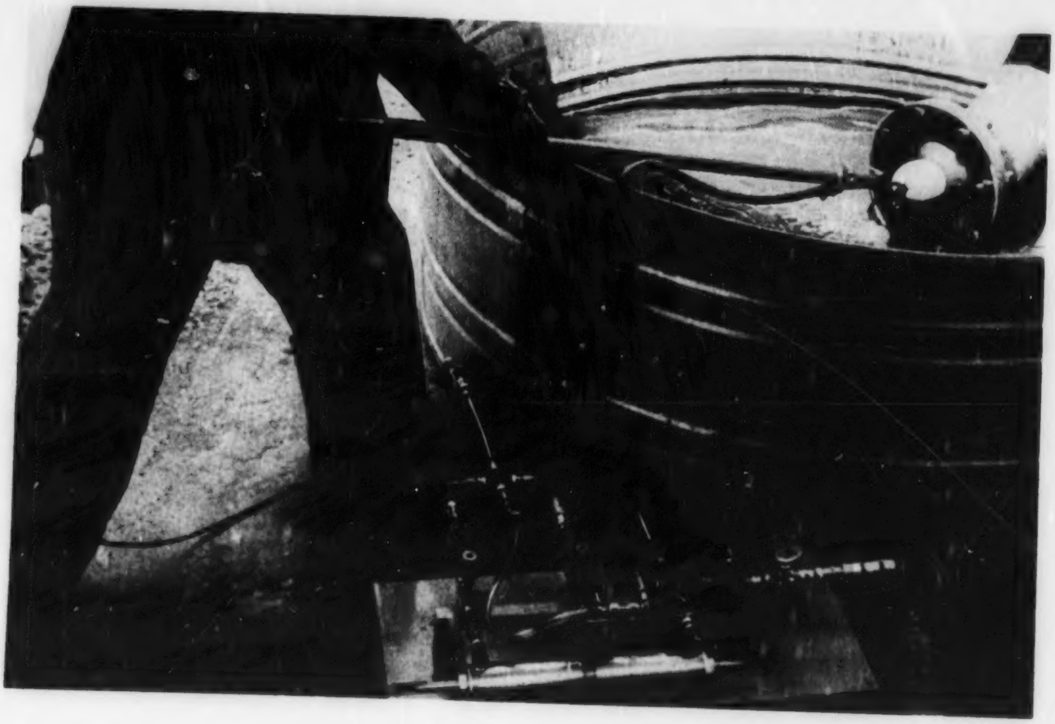

Figure 22. Applicator Just Inserted Into Leak

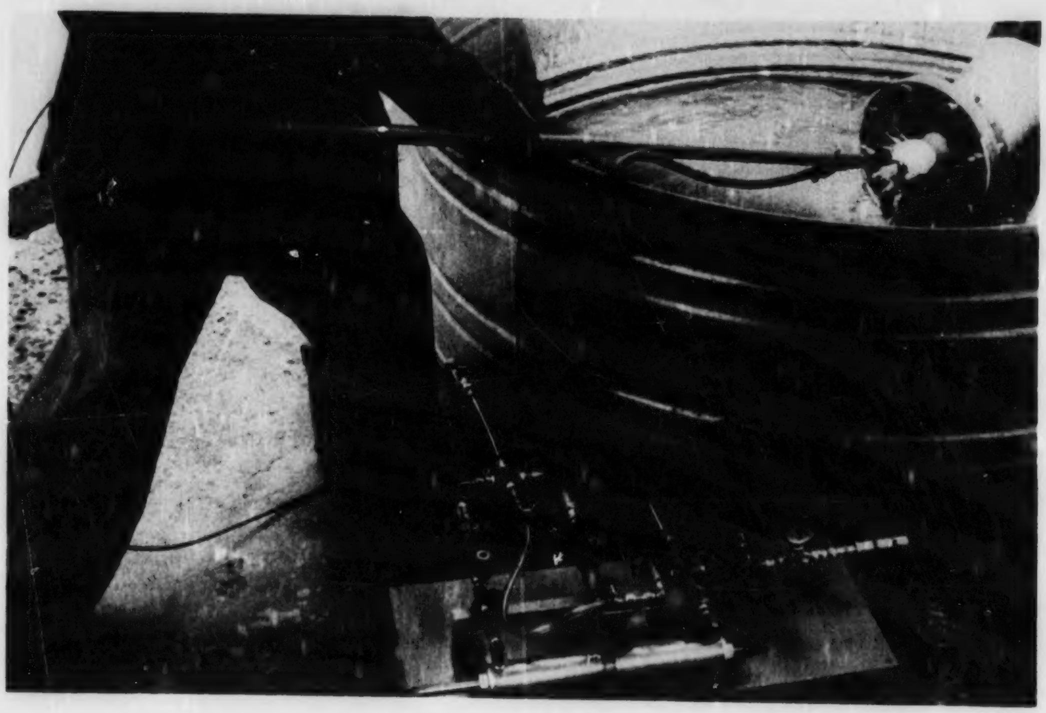

Figure 23. Leak Slows as Applicator Expands

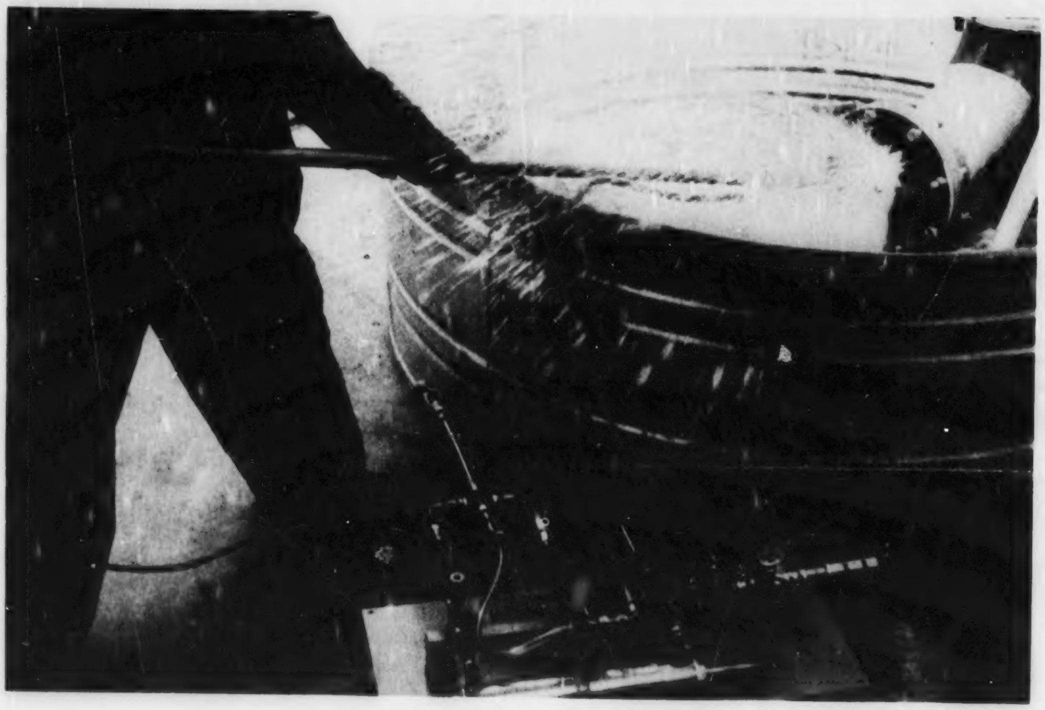

Figure 24. Leak Stopped by Full Applicator Expansion

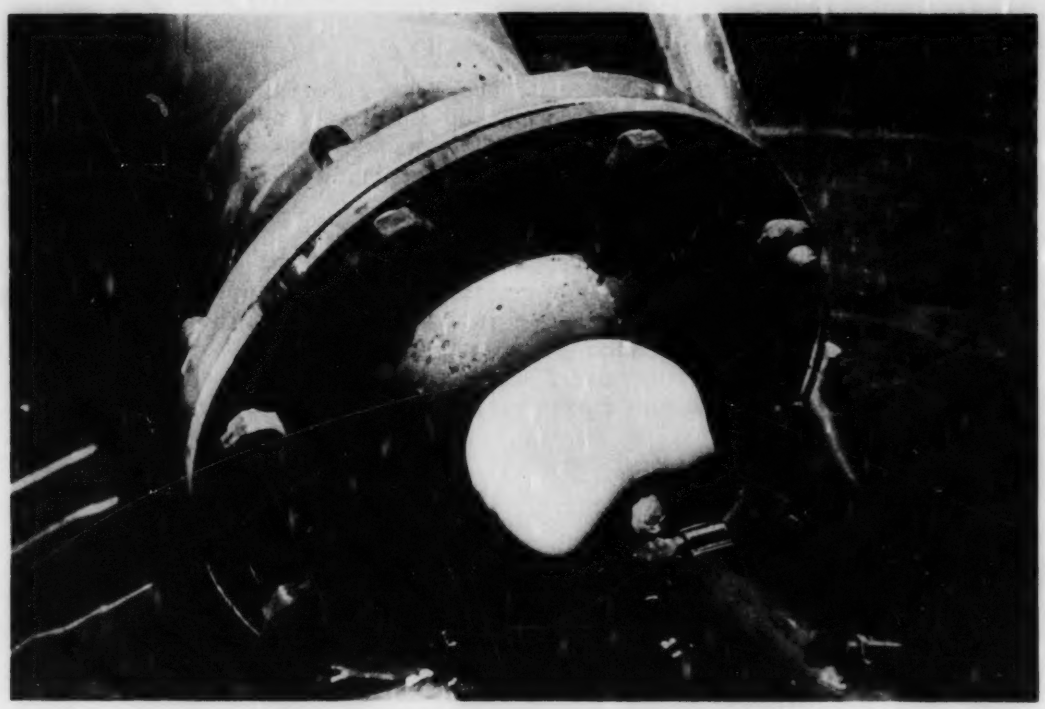

Figure 25. Close-Up of Completed Plug

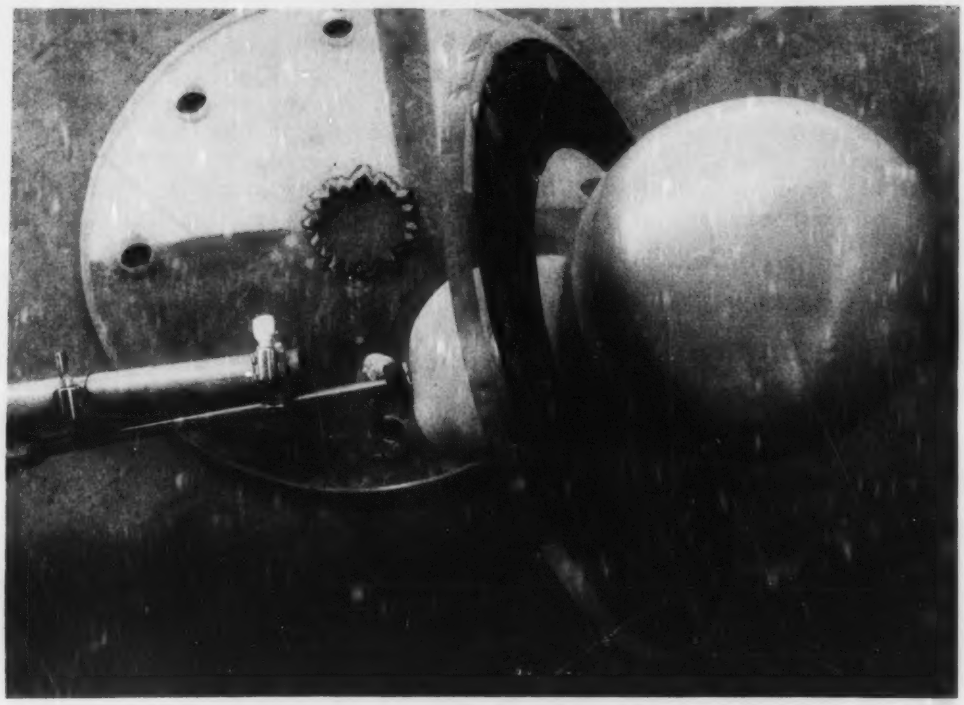

Figure 26. Completed Plug After Removal From Tank

distance to where the balance of the leak-plugging equipment has been placed, and repeats the procedure above using a new set of equipment or refilling the delivery system with foam chemicals and installing a new applicator tip. A description of the refilling procedure is given in Appendix B.

The prototype delivery systems are intended as one-shot devices before recharging with foam chemicals. Similar systems could be constructed with large cylinders and used to plug more than one hole before delivery system must be refilled. Such a large system would use a series of mechanical stops to limit the travel distance of the pistons during each shot. This stop would have to be repositioned by the operator after each shot.

Post-Operation Considerations

The life of the installed plug depends upon a number of factors. A design goal for this program was to provide a life of approximately 24 hours. Actual life of plugs when the prototype systems are used will probably be much longer than this if chemical compatibility is not a problem; i.e., it is expected that plug life will depend upon chemical compatibility considerations rather than upon mechanical or physical factors.

Should it be essential, the protruding metal delivery tube and spacer subassembly can be cut away with a hacksaw after allowing about 1/2 hour for the plug to attain maximum structural strength. However, unnecessary and forced straining of the plug is not desirable, since the foam is somewhat crushable and only slightly elastic. If the crushing strength of the foam at the ragged edge of the hole were exceeded by some externally applied force, then increased leakage would be likely. Thus, if movement is forced, usually any leakage remaining will be increased. Therefore, any unnecessary cutting, handling, or manipulating of the plug should be avoided. On the other hand, the foam, once cured, is very strong and rigid if the plug has been properly formed. For example, the protruding parts of completed plugs have supported the weight of a man without major damage.

OBSERVATIONS FROM PROTOTYPE TESTING

The final prototype gave very satisfactory performance in plugging leaks of various sizes and under a variety of conditions. Additional work is needed to further improve its reliability and repeatability when used in more difficult cases (e.g., with very high liquid heads, large holes, or at low temperatures).

Demonstration tests were made and filmed (Ref. 5) with the prototype nearly in final form. Subsequently, the spacer subassembly (shown in Fig. 16) was added to the applicator near the end of the program. This feature was of considerable help in eliminating much operator skill and judgment in positioning the applicator tip in the leaking hole.

Some other observations and suggestions for the prototype user are briefly outlined in the remainder of this subsection. A detailed description of the prototype capabilities and operating characteristics is given in the next subsection.

The reliability of obtaining a good seal decreases as the head pressure increases, not only because of difficulty experienced by the operator in holding the applicator in the hole against the internal tank pressure, but also because of the reduced volume of foam obtained when it is forced to expand against a higher tank pressure.

It is estimated that the quantity of foam required increases roughly as the cube of the hole diameter. Thus, the size of the applicator tip and quantity of foam chemicals delivered to the applicator tip ideally should be changed somewhat for large variations in hole size.

At low temperatures, there is a tendency to deliver a smaller volume of foam, other factors being equal. The exact relationship is not simple, however, since temperature effects are also related to mixing and foam-curing effects which help but are difficult to quantify. This complicated contribution of mixing and curing occurs because the foam mixture, once well mixed even though cold, soon warms because of the exothermic character of the reaction between the two chemicals and their inherently good insulating qualities. Even a slight amount of reaction will generate heat and raise the temperature slightly, which in turn will strongly increase the reaction rate, producing even more heat, etc. This exothermic process ultimately causes a very rapid reaction and rapid foaming. Although this mechanism requires a longer time to start at low temperatures, once started the reaction proceeds to completion and the temperature inside the foam appears to be not greatly different from that obtained by starting with the chemicals at normal temperatures, provided, that the two chemicals are well mixed.

There is an important factor which permits mitigation of the requirement for having a precise amount of foam delivered to the applicator tip, depending upon the hole size, head pressure, and chemical temperatures. This factor is that the final size of the expanded applicator tip reached at the end of the plugging operation can be far greater than is necessary without causing any problems. Having far too great a quantity of foam does not hurt the quality of the seal; having too little, of course, prevents successful leak plugging. Therefore, the quantity of foam should always be set to be the maximum allowable and limited only by the size and elongation of the outside membrane of the applicator. Having the outside membrane burst, either inside or outside the tank, is almost always undesirable since it allows the tank fluid to come into contact with the foam.

OPERATING CHARACTERISTICS

Particular attention was given during the prototype development work to considerations of safety, ease of use, lightness of weight, rapid-response capability, and other features that are important in a practical operational system. These goals and corresponding capabilities of the prototype are discussed in this section.

A broad range of goals for system operating characteristics were listed at the beginning of this effort to serve as guidelines for prototype system development. These goals are as follows:

1. No external power requirements
2. No secondary pollution problems
3. Allows salvage of hazardous chemical remaining in tank
4. Permanent or long-term plugging
5. Rapid response
6. Usable with dry, dirty, and wet surfaces
7. Moderate weight and portability (use by one man)
8. Long shelf life
9. Reasonable cost
10. Compatible with wide range of hazardous chemicals
11. Ability to completely plug leaks
12. Safe and easy to use by untrained personnel
13. Flexibility in hole size, shape, location, etc.
14. Usable with liquid heads as high as those encountered in tank cars
15. Wide temperature tolerance (both in storage and application)

Each of these goals has been achieved, at least to a sufficient extent to permit satisfactory use of the prototype leak-plugging system. The individual goals and corresponding system characteristics are discussed in the following subsections (numbered according to the list of goals above).

1. No External Power Requirements. The system is completely portable and self-contained. Only a small cartridge containing liquid carbon dioxide is required to perform the tasks of delivering and mixing the two foam chemicals. The standard cartridges are widely available in wholesale or retail stores, inexpensive, and weigh only a couple of ounces.
2. No Secondary Pollution Problems. Absolutely no secondary pollution problems are caused by the leak-plugging system. This is further discussed under subsection 3 below.

3. Allows Salvage of Hazardous Chemicals Remaining in the Tank. This leak-plugging system stops the leakage of the chemical, thus retaining it in the original tank. No foreign materials (e.g., gelling agents) are introduced into the chemical. The present system inherently does not contaminate the chemicals in the tanks because the applicator membrane forms a barrier between the hazardous chemical and the urethane foam. If the chemical resistance of the membrane is adequate through the period of leak plugging, i.e., is not attacked or dissolved by the chemical, then there will be no contamination of the chemicals in the tank. Even in unusual cases where there is some failure of the membrane, there may be at most very minor quantities of urethane foam or rubber membrane material introduced into the tank.

4. Permanent or Long-Term Plugging. In an emergency, any kind of even very temporary plugging of a hazardous chemical leak is welcomed, provided it is not dangerous to implement. Thus even a plug lasting 1 or 2 hours might be vital in an emergency, were it available. With the prototype system, the life of a completed plug is variable, depending almost entirely on the chemical compatibility of the applicator tip membrane. In general, the life will easily achieve the 24-hour time requirement set as a goal, depending upon the compatibility of the membranes utilized with the particular chemical leak that is being sealed. By appropriately choosing the proper membranes, the plug may last up to weeks or months.

   In those cases where adequately inert membranes cannot be found to achieve at least a 24-hour life (which is true for only a few chemicals), there may still be obtained a life of a few hours. Even a reduced period will provide time to take other action.

5. Rapid Response. A minimum response time is, of course, desired. The present system has a response time close to the minimum of any imaginable which is still practical. Arrival at the site with corrective gear and personnel as soon as possible after discovery of the leak is important. The present equipment is small and inexpensive enough so that many units can be appropriately placed on actual transportation vehicles (trucks, trains, ships) or in local fire stations. The response time is reduced greatly as the number of systems that can be deployed is increased.

   The second part of the response time is that required to plug the leak after arrival at the site. This is made up of times to unpack equipment from the vehicle, don protective clothing, and perform the actual leak plugging. Present estimates, based on testing with the prototype during this program, assign the following times to these steps (assuming that the leak-plugging system and an operator who is familiar with the system are at the site in advance)

Unpacking equipment	30 to 60 seconds
Donning protective clothing	40 to 60 seconds
System adjustment and moving to leak	20 to 60 seconds
Plugging of the leak	30 to 50 seconds
Total	2 to 3 minutes

These times could vary considerably, depending on location of the leak and damaged tank, weather conditions, operator experience, etc. In any case, the total time for use of the equipment is short compared with the time required for arrival at the site.

6. Usable With Dry, Dirty, and Wet Surfaces. The system does not depend at all on the adhesive qualitites of materials to achieve a seal. Rather, it depends on the shape and rigidity of the expanded applicator tip to maintain an adequate plug. Therefore, the condition of the tank wall surface is totally unimportant.

7. Moderate Weight and Portability. One man can deploy, mount, and use the prototype system by himself. However, it is desirable to have a second individual standing by at a relatively safe distance to observe the operator, in case of an emergency in which the operator may need help. If a second individual is available, he also can speed up deployment and mounting of the equipment. The actual leak plugging should be a single-man operation (which also reduces the total risk exposure).

8. Long Shelf Life. The shelf life of the delivery system is primarily determined by the storage life of the foam components and the long-term compatibility of those chemicals with the seal materials in the delivery system. Long-term storability tests should be a part of the production development effort. A period of 6 months to 2 years between equipment servicing appears to be a reasonable expectation.

   The estimated shelf life of the applicator tips is limited only by any deterioration of the membrane materials. Ozone can degrade some rubber membranes rapidly. Long-term shelf life should be one of the factors in final membrane material selection.

   Applicator tips might be stored in the field in sealed containers under a slight positive pressure of dry nitrogen or other relatively inert gas. The "crack-type" applicator should be stored in an evacuated tubular container.

9. Reasonable Cost. The estimated costs to duplicate the delivered prototype leak-plugging system are given below (at 1974 prices). Material costs are actual costs taken from the fabrication of the prototype during this program; labor costs are estimates for a batch production run of 50 systems.

Foam delivery system (mechanically operated prototype):			
	Material	$304	
	Labor	$400	
		$704	$704
Applicators:			
	Material	$ 31 each	
	Labor	$ 25 each	
		$ 56	
Three applicators at		$ 56 each	$168
One handle at		$ 8 each	$ 8
Storage container			$ 20
Total direct cost (not commercial sales price)			$900

It is expected that the cost to fabricate production models, after a production development program, could be considerably lower than the figures above.

Equipment for refilling the foam delivery system in the field will cost approximately $150 each to fabricate, plus chemicals. The foam components cost about $100 commercially for a pair of cylinders containing a total of approximately 45 kg (100 pounds) of chemicals. This is enough for about 100 leak pluggings, giving a foam cost per plugging of approximately $1.

10. Compatible With Wide Range of Hazardous Chemicals. Large improvement in the chemical compatibility of the plugs was achieved during this program by using a membrane on the outside of the applicator to physically separate the curing foam and the hazardous chemical. It is expected that membranes of different materials can be used to permit plugging of virtually all of the chemicals expected to be designated as "hazardous substances" under 40CFR Part 116 (Ref. 4).

The predicted system capability, including materials compatibility considerations, is summarized in Table 4, which lists the 300-plus hazardous chemicals given in Ref. 4. An explanation of symbols used in Table 4 follows: An "x" in Table 4 indicates an affirmative answer to the question at the top of the column. The numbers in the "Other Limits on Sealing" column refer to the relative risk to the leak-plugging operator, with 3 being the highest and 1 the lowest risk. Parentheses around an "x" indicate a marginal evaluation or conditional judgment is also involved. The evaluation of whether the vapor pressure is too high for leak plugging was done in relation to the capabilities of the present leak sealing system. It may be possible to develop the method further, to enable higher pressure leaks to be sealed.

It can be seen from Table 4 that there are very few hazardous chemicals that are judged to be not feasible for leak plugging with the present system. Limitations on the applicability of the system are seldom caused solely by materials compatibility

TABLE 4. PROBABLE LEAK-PLUGGING SUCCESS WITH HAZARDOUS CHEMICALS LISTED IN 40 CFR PART 116 (REF. 4)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Acetaldehyde	ethanal ethyl aldehyde aldehyde acetic aldehyde	x	
Acetic acid	glacial acetic acid vinegar acid	x	
Acetic anhydride	acetic oxide acetyl oxide	x	
Acetone cyanohydrin	2-methyllactonitrile alpha-hydroxyisobutyronitrile	x	
Acetyl bromide			x 2*
Acetyl chloride			x 2*
Acrolein	2-propenal acrylic aldehyde acrylaldehyde acraldehyde	x	
Acrylonitrile	cyanoethylene Fumigrain Ventox propenenitrile vinyl cyanide	x	
Adiponitrile	1,4-dicyanobutane	x	
Aldrin	Octalene HHDN	x	
Allyl alcohol	2-propen-1-ol 1-propenol-3 vinyl carbinol	x	
Allyl chloride	3-chloropropene 3-chloropropylene Chlorallylene	x	
Aluminum sulfate	alum	x	
Ammonia			x 2
Ammonium compounds:			
Ammonium acetate	acetic acid ammonium salt	x	
Ammonium benzoate		x	
Ammonium bicarbonate	acid ammonium carbonate ammonium hydrogen carbonate	x	
Ammonium bisulfite		x	
Ammonium bromide		x	
Ammonium carbamate	ammonium aminoformate	x	
Ammonium carbonate		x	
Ammonium chloride	ammonium muriate sal ammoniac salmiac Amchlor	x	
Ammonium citrate, dibasic	diammonium citrate citric acid diammonium salt	x	
Ammonium fluoborate		x	
Ammonium hydroxide		x	
Ammonium hypophosphite		x	
Ammonium iodide		x	

*Numbers refer to relative risk; 3 is highest, 1 is lowest.

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Ammonium compounds (continued)			
Ammonium nitrate		x	
Ammonium oxalate		x	
Ammonium pentaborate	ammonium decaborate	x	
Ammonium persulfate	ammonium peroxydisulfate	x	
Ammonium silicofluoride	ammonium fluosilicate	x	
Ammonium sulfamate	Ammate AMS ammonium amidosulfate	x	
Ammonium sulfide			(x) 2
Ammonium sulfite		x	
Ammonium tartrate	tartaric acid ammonium salt	x	
Ammonium thiocyanate	ammonium rhodanide ammonium sulfocyanate ammonium sulfocyanide	x	
Ammonium thiosulfate	ammonium hyposulfite	x	
Amyl acetate	amylacetic ester pear oil banana oil (isomers are normal-, iso-, secondary-, tertiary-amyl acetate)	x	
Aniline	aniline oil phenylamine aminobenzene aminophen kyanol	x	
Antimony compounds:			
Antimony pentachloride		x	
Antimony pentafluoride		x	
Antimony potassium tartrate	tartar emetic tartrated antimony tartarized antimony potassium antimonyltartrate	x	
Antimony tribromide		x	
Antimony trichloride	butter of antimony	x	
Antimony trifluoride	antimony fluoride	x	
Antimony trioxide	dianitmony trioxide flowers of antimony	x	
Arsenic compounds:			
Arsenic acid	orthoarsenic acid	x	
Arsenic disulfide	arsenic monosulfide red arsenic sulfide	x	
Arsenic pentaoxide	arsenic acid anhydride arsenic oxide	x	
Arsenic trichloride	arsenic chloride arsenious chloride arsenous chloride butter of arsenic	x	
Arsenic trioxide	arsenious acid arsenious oxide white arsenic	x	
Arsenic trisulfide	arsenious sulfide yellow arsenic sulfide	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Arsenic compounds (continued)			
Calcium arsenate	tricalcium ortho-arsenate	x	
Calcium arsenite		x	
Potassium arsenate		x	
Potassium arsenite	potassium metaarsenite	x	
Sodium arsenate	disodium arsenate	x	
Sodium arsenite	sodium metaarsenite	x	
Benzene	cyclohexatriene benzol	x	
Benzoic acid	benzenecarboxylic acid phenylformic acid dracylic acid	x	
Benzonitrile	phenyl cyanide cyanobenzene	x	
Benzoyl chloride	benzenecarbonyl chloride		(x) 2
Benzyl chloride		x	
Beryllium compounds			
Beryllium chloride		x	
Beryllium fluoride		x	
Beryllium nitrate		x	
Butyl acetate	acetic acid normal-butyl ester acetic acid secondary-butyl ester acetic acid iso-butyl ester acetic acid tertiary-butyl ester (isomers are normal-, secondary, iso-, tertiary-butyl acetate)	x	
Butylamine	1-; 2-aminobutane 2-amino-2-methylpropane 1-amino-2-methylpropane (isomers are normal-, secondary-, tertiary-butylamine)	x	
Butyric acid	butanoic acid ethylacetic acid (isomers are normal-, iso-butyric acid)	x	
Cadmium compounds			
Cadmium acetate		x	
Cadmium bromide		x	
Cadmium chloride		x	
Calcium carbide	carbide acetylenogen	x	(x) 2
Calcium hydroxide	hydrated lime slaked lime calcium hydrate	x	
Calcium hypochlorite		x	
Calcium oxide	lime quicklime	x	
Captan	Orthocide-406 SR-406 Vancide-89	x	
Carbaryl	Sevin	x	
Carbon disulfide	carbon bisulfide dithiocarbonic anhydride	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Cadmium compounds (continued)			
Chlordane	Toxichlor	x	
Chlorine			x 3
Chlorobenzene	monochlorobenzene benzene chloride	x	
Chloroform	trichloromethane	x	
Chlorosulfonic acid	sulfuric chlorohydrin		x 3
Chromium compounds:			
Ammonium bichromate	ammonium dichromate	x	
Ammonium chromate		x	
Calcium chromate	calcium chrome yellow gelbin yellow ultramarine	x	
Chromic acetate		x	
Chromic acid	chromic anhydride chromium trioxide		x 2
Chromic sulfate		x	
Chromous chloride		x	
Chromyl chloride	chromium dioxychloride	x	
Lithium bichromate	lithium dichromate	x	
Lithium chromate		x	
Potassium bichromate	potassium dichromate	x	
Potassium chromate		x	
Sodium bichromate	sodium dichromate	x	
Sodium chromate		x	
Strontium chromate		x	
Zinc bichromate	zinc dichromate	x	
Cobalt compounds:			
Cobaltous bromide	cobalt bromide	x	
Cobaltous fluoride	cobalt fluoride	x	
Cobaltous formate	cobalt formate	x	
Cobaltous sulfamate	cobalt sulfamate	x	
Copper compounds:			
Cupric acetate	copper acetate crystallized verdigris	x	
Cupric acetoarsenite	copper acetoarsenite copper acetate arsenite Paris green	x	
Cupric chloride	copper chloride	x	
Cupric formate	copper formate	x	
Cupric glycinate	copper glycinate cupric aminoacetate	x	
Cupric lactate	copper lactate	x	
Cupric nitrate	copper nitrate	x	
Cupric oxalate	copper oxalate	x	
Cupric subacetate	basic copper acetate	x	
Cupric sulfate	copper sulfate	x	
Cupric sulfate, ammoniated	ammoniated copper sulfate	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Copper compounds (continued)			
Cupric tartrate	copper tartrate	x	
Cuprous bromide	copper bromide	x	
Coumaphos	Co-Ral	x	
Cresol	cresylic acid hydroxytoluene (isomers are meta-, ortho-, para-cresol)	x	
Cyanide compounds:			
Barium cyanide		x	
Calcium cyanide		x	
Hydrogen cyanide	hydrocyanic acid		x 2
Potassium cyanide		x	
Sodium cyanide		x	
Zinc cyanide		x	
Cyanogen chloride			x 3
Cyclohexane	hexahydrobenzene hexamethylene hexanaphthene	x	
2,4-D (acid)	2,4-dichlorophenoxyacetic acid	x	
2,4-D (esters)	2,4-dichlorophenoxyacetic acid esters	x	
Dalapon	Dowpon Gramevin Radapon Unipon	x	
DDT	p,p'-DDT	x	
Diazinon	Dipofene Diazitol Basudin Spectracide	x	
Dicamba	2-methoxy-3,6-dichlorobenzoic acid	x	
Dichlobenil	2,6-dichlorobenzonitrile 2,6-DBN	x	
Dichlone	Phygon dichloronaphthoquinone	x	
Dichlorvos	2,2-dichlorovinyl dimethyl phosphate Vapona	x	
Dieldrin	Alvit	x	
Diethylamine		x	
Dimethylamine			x 1
Dinitrobenzene	dinitrobenzol	x	
Dinitrophenol	Aldifen (isomers are 2,3-;2,4-;2,5-;2,6-;3,4-;3,5-dinitrophenol)	x	
Diquat	Aquacide Dextrone Reglone Diquat dibromide	x	
Disulfoton	Di-syston	x	
Diuron	DCMU DMU	x	
Dodecylbenzenesulfonic acid		x	
Dodecylbenzenesulfonic acid, calcium salt		x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Cyanide compounds (continued)			
Dodecylbenzenesulfonic acid, isopropanolamine salt		x	
Dodecylbenzenesulfonic acid, sodium salt		x	
Dodecylbenzenesulfonic acid, triethanolamine salt		x	
Dursban	chlorpyrifos	x	
Endosulfan	Thiodan	x	
Endrin	Mendrin Compound 269	x	
Ethion	Nialate	x	
Ethylbenzene		x	
Ethylenediamine	1,2-diaminoethane	x	
Ethylenediamine-tetraacetic acid	EDTA edetic acid Havidote (ethylenedinitrilo)-tetraacetic acid	x	
Fluorine compounds:			
Aluminum fluoride	aluminum trifluoride	x	
Ammonium bifluoride	acid ammonium fluoride ammonium hydrogen fluoride	x	
Ammonium fluoride	neutral ammonium fluoride	x	
Hydrofluoric acid	fluohydric acid		x 3
Sodium bifluoride		x	
Sodium fluoride	villiaumite	x	
Stannous fluoride		x	
Formaldehyde	methyl aldehyde		(x)2
	methanal		(x)2
	formalin	x	
Formic acid	methanoic acid	x	
Fumaric acid	trans-butenedioic acid trans-1,2-ethylenedicarboxylic acid boletic acid allomaleic acid	x	
Furfural	2-furaldehyde pyromucic aldehyde	x	
Guthion	Gusathion azinphos-methyl	x	
Heptachlor	Velsicol-104 Drinox Heptagran	x	
Hydrochloric acid	hydrogen chloride		x 2
	muriatic acid	x	
Hydroxylamine	oxammonium	x	
Iron compounds:			
Ferric ammonium citrate	ammonium ferric citrate	x	
Ferric ammonium oxalate	ammonium ferric oxalate	x	
Ferric chloride	flores martis iron trichloride	x	
Ferric fluoride		x	
Ferric nitrate	iron nitrate	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Iron compounds (continued)			
Ferric sulfate	ferric persulfate ferric sesquisulfate ferric tersulfate	x	
Ferrous ammonium sulfate	Mohr's salt iron ammonium sulfate	x	
Ferrous chloride	iron chloride iron dichloride iron protochloride	x	
Ferrous sulfate	green vitriol iron vitriol iron sulfate iron protosulfate	x	
Isoprene	2-methyl-1,3-butadiene	x	
Kelthane	di(p-chlorophenyl)-trichloromethylcarbinol DTMC dicofol	x	
Lead compounds:			
Lead acetate	sugar of lead	x	
Lead arsenate		x	
Lead chloride		x	
Lead fluoborate		x	
Lead fluoride	lead difluoride plumbous fluoride	x	
Lead iodide		x	
Lead nitrate		x	
Lead stearate	stearic acid lead salt	x	
Lead sulfate		x	
Lead sulfide	galena	x	
Lead tetraacetate		x	
Lead thiocyanate	lead sulfocyanate	x	
Lead thiosulfate		x	
Lead tungstate		x	
Lindane	gamma-BHC gamma-benzene hexachloride	x	
Malathion	phosphothion	x	
Maleic acid	cis-butenedioic acid cis-1,2-ethylenedicarboxylic acid toxilic acid	x	
Maleic anhydride	2,5-furandione cis-butenedioic anhydride toxilic anhydride	x	
Mercury compounds:			
Mercuric acetate	mercury acetate	x	
Mercuric cyanide	mercury cyanide	x	
Mercuric nitrate	mercury nitrate mercury pernitrate	x	
Mercuric sulfate	mercury sulfate mercury persulfate mercury bisulfate	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Mercury compounds (continued)			
Mercuric thiocyanate	mercury thiocyanate mercuric sulfocyanate mercuric sulfocyanide	x	
Mercurous nitrate	mercury protonitrate	x	
Methoxychlor	DMDT methoxy-DDT	x	
Methyl mercaptan	methanethiol mercaptomethane methyl sulfhydrate thiomethyl alcohol	x	
Methyl methacrylate	methacyrlic acid methyl ester methyl-2-methyl-2-propenoate	x	
Methyl parathion	Nitrox-80	x	
Mevinphos	Phosdrin	x	
Monoethylamine	ethylamine aminoethane		x 1
Monomethylamine	methylamine aminomethane		x 1
Naled	Dibrom	x	
Naphthalene	white tar tar camphor naphthalin	x	
Naphthenic acid	cyclohexanecarboxylic acid hexahydrobenzoic acid	x	
Nickel compounds			
Nickel ammonium sulfate	ammonium nickel sulfate	x	
Nickel chloride	nickelous chloride	x	
Nickel formate		x	
Nickel hydroxide	nickelous hydroxide	x	
Nickel nitrate		x	
Nickel sulfate	nickelous sulfate	x	
Nitric acid	aqua fortis		x 2
Nitrobenzene	nitrobenzol oil of mirbane	x	
Nitrogen dioxide	nitrogen tetraoxide		x 3
Nitrophenol	mononitrophenol (isomers are meta-, ortho-, para-nitrophenol)	x	
Paraformaldehyde	Paraform Formagene Triformol polymerized formaldehyde polyoxymethylene	x	
Parathion	DNTP Niran	x	
Pentachlorophenol	PCP Penta	x	
Phenol	carbolic acid phenyl hydroxide hydroxybenzene oxybenzene	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Phosgene	diphosgene carbonyl chloride chloroformyl chloride		x 3
Phosphoric acid	orthophosphoric acid	x	(x)2
Phosphorus	black phosphorus	x	
	red phosphorus	x	
	white phosphorus		x 3
	yellow phosphorus		x 3
Phosphorus oxychloride	phosphoryl chloride phosphorus chloride		(x)2
Phosphorus pentasulfide	phosphoric sulfide thiophosphoric anhydride phosphorus persulfide	x	
Phosphorus trichloride	phosphorous chloride		x 2
Polychlorinated biphenyls	PCB Aroclor Polychlorinated diphenyls	x	
Potassium hydroxide	potassium hydrate caustic potash potassa	x	
Potassium permanganate	chameleon mineral	x	
Propionic acid	propanoic acid methylacetic acid ethylformic acid	x	
Propionic anhydride	propanoic anhydride methylacetic anhydride	x	
Propyl alcohol	ethyl carbinol propylic alcohol propanol (isomers are normal-, iso-propyl alcohol)	x	
Pyrethrins	Pyrethrin I Pyrethrin II	x	
Quinoline	1-benzazine benzo[b]pyridine leucoline chinoleine leucol	x	
Resorcinol	resorcin 1,3-benzenediol meta-dihydroxybenzene	x	
Selenium compounds:			
Selenium oxide	selenium dioxide	x	
Sodium selenite		x	
Sodium	natrium		(x)2
Sodium bisulfite	sodium acid sulfite sodium hydrogen sulfite	x	
Sodium hydrosulfide	sodium sulfhydrate	x	
Sodium hydroxide	caustic soda soda lye sodium hydrate	x	
Sodium hypochlorite	bleach	x	
Sodium methylate	sodium methoxide	x	

TABLE 4. (Concluded)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Sodium nitrite		x	
Sodium phosphate, dibasic		x	
Sodium phosphate, monobasic		x	
Sodium phosphate, tribasic		x	
Sodium sulfide		x	
Strychnine		x	
Styrene	vinylbenzene phenylethylene styrol styrolene cinnamene cinnamol	x	
Sulfuric acid	oil of vitriol oleum		(x)2
Sulfur monochloride	sulfur chloride	x	
2,4,5-T (acid)	2,4,5-trichlorophenoxyacetic acid	x	
2,4,5-T (esters)	2,4,5-trichlorophenoxyacetic esters	x	
TDE	DDD	x	
Tetraethyl lead	lead tetraethyl TEL	x	
Tetraethyl pyrophosphate	TEPP	x	
Toluene	toluol methylbenzene phenylmethane Methacide	x	
Toxaphene	camphechlor	x	
Trichlorfon	Dipterex Dylox	x	
Trichlorophenol	Collunosol Dowicide 2 or 2S Omal Phenachlor	x	
Triethylamine		x	
Trimethylamine	TMA		x 2
Uranium compounds:			
Uranium peroxide		x	
Uranyl acetate		x	
Uranyl nitrate		x	
Uranyl sulfate		x	
Vanadium compounds:			
Vanadium pentoxide	vanadic anhydride vanadic acid anhydride	x	
Vanadyl sulfate	vanadic sulfate vanadium sulfate	x	
Vinyl acetate	acetic acid ethylene ether	x	
Xylene	dimethylbenzene xylol (isomers are meta-, ortho-, para-xylene)	x	
Xylenol	dimethylphenol hydroxydimethyl benzene	x	
Zectran	mexacarbate	x	

TABLE 4. (Continued)

Hazardous Chemical		Leak-Plugging System Applicable	Other Limits on Plugging a Leak
Common Name	Synonyms		
Zinc compounds:			
Zinc acetate		x	
Zinc ammonium chloride		x	
Zinc borate		x	
Zinc bromide		x	
Zinc carbonate		x	
Zinc chloride	butter of zinc	x	
Zinc fluoride		x	
Zinc formate		x	
Zinc hydrosulfite		x	
Zinc nitrate		x	
Zinc phenolsulfonate	zinc sulfocarbolate	x	
Zinc phosphide		x	
Zinc potassium chromate	zinc yellow citron yellow buttercup yellow zinc chrome	x	
Zinc silicofluoride	zinc fluosilicate	x	
Zinc sulfate	white vitriol zinc vitriol white copperas	x	
Zinc sulfate, monohydrate		x	
Zirconium compounds:			
Zirconium acetate		x	
Zirconium potassium fluoride		x	
Zirconium nitrate		x	
Zirconium oxychloride	zirconyl chloride zirconium chloride, basic		(x)2
Zirconium sulfate	disulfatozirconic acid	x	
Zirconium tetrachloride		x	

NOTE 1: When both columns are marked, the plugging capability depends on such factors as the weather, humidity, and spill location (e.g., underwater versus air).

NOTE 2: Some so-called synomyns actually refer to different physical forms of the compound. If so, they may affect the "plugability" rating.

limitations, i.e., where materials compatibility is a problem, the vapor pressure is also excessively high, and/or the risk to operator personnel is high.

A neoprene membrane fulfills the compatibility requirement for the great majority of the materials in the list of 300-plus hazardous chemicals (Table 4). Buna-N and polyimid polyester materials cover most of those remaining. Should a material be found that is not compatible with the three above, silicone rubber should be considered; also a possibility exists that a membrane made of polytetrafluoroethylene, PTFE (Teflon), can be used. This would result in a combination of membrane materials compatible with essentially all the chemicals in the list. Leak-plugging tests have been made with neoprene and polyimid polyester membranes; expected Buna-N applicability is based on published compatibility information obtained from glove manufacturers and chemical laboratory wear manufacturers.

It is also possible to use two membranes, one surrounding the other, to achieve the desired combination of chemical and physical properties for difficult chemicals. This was done to seal an ethylene trichloride leak where an ordinary latex membrane (which is attacked by ethylene trichloride) was used inside a relatively large, thin, polyimid bag. The outside bag was thin, strong, and roomy while the inside bag was extremely elastic and served also to compress the sponge in the applicator tip, making insertion easier. The outside bag was folded and lightly tacked in place with a fastener strong enough to keep it in place during insertion, but weak enough so that it easily loosened during expansion of the foam inside the applicator.

11. Ability to Completely Plug Leaks. The completeness of the leak plugging depends primarily on the irregularity of the edges of the hole to be plugged. With fairly regular, smooth-edged holes, it is not uncommon to produce a completely tight seal. Even with very irregular holes, the flow will be reduced to a few percent of the original leak.

12. Safe and Easy to Use by Untrained Personnel. This subject is discussed in the next part of Section VI, "Implementation Plan." In summary, the leak-plugging system does not require much operator skill. It could be used by someone completely unfamiliar with the system. However, the speed and, to some extent, the success of a leak-plugging operation will be improved by providing a potential operator with a brief checkout and test use of the system in advance of an emergency situation.

The safety issues in the use of the system arise from the potential hazards of the leaking chemical itself. The applicator poles in the delivered prototypes are about 2.5 meters (7.5 feet) long. This moves the operator partly back away from the splash zone. However, protective clothing should be worn by the operator. Further, during planning for deployment careful attention should be given to identify hazardous chemicals which are too dangerous for practical plugging (except by highly trained and well-equipped emergency personnel). Table 4 represents a preliminary estimate of those chemicals which could be handled by trained personnel; leaks of some of these chemicals should not be plugged by unskilled personnel.

13. Flexibility in Hole Size, Shape, and Location. The present leak-plugging system permits successful plugging with considerable flexibility in hole size, shape, and location. Successful tests have been made with holes from 2.5 cm (1 inch) to 10 cm (4 inches) across, cracks 1.3 cm (1/2 inch) by 15 cm (6 inches), and with various shapes and degrees of jaggedness (including ragged holes cut in the plane of the tank wall and also punctured holes with rough sections in three dimensions). The applicator tip design (with an outer membrane) does impose some constraints on the ability of the tip to expand into very small crevices and irregularities at the edges of a hole. However, the expansion both inside and outside the tank wall tends to block and plug even considerable irregularities.

    It is expected that the present leak-plugging concept can be used over an even wider range of hole sizes than tested to date. With a variety of applicator tip sizes and shapes, together with a variable-volume foam supply device, it should be possible to plug holes from about 1 cm (1/2 inch) to 30 cm (12 inches) across, and cracks as thin as 0.3 cm (1/8 inch). The capabilities in hole size are related to liquid heads and temperature. This is further discussed in the next subsection.

    The present method permits insertion of the applicator at almost any angle and therefore provides wide flexibility in hole location. Any hole into which an operator can insert the end of a long stick can usually be plugged using the present method. The angle between the axis of the applicator and the surface of the tank at the hole need not be 90 degrees; it can be as low as 20 degrees and still obtain a satisfactory plug.

    Successful leak-plugging tests were made also with leaks submerged under water. There is no additional difficulty in plugging leaks under water, as compared with in air, except for operator access and visibility.

14. Usable With Liquid Heads as High as Those Encountered in Tank Cars. The prototype system has been used successfully to plug leaks against liquid heads as high as those encountered in tank cars. Any limitations on allowable liquid head result primarily from human strength plus logistics considerations, not from inherent limitations in the leak-plugging system. The practical range of liquid heads against which leaks can be plugged depends on several factors, including leak size, elevation of the leak relative to the tank, tank volume and proportions, orientation of the tank, and fluid density. This is further discussed below.

The volume of tank trucks and trailers for highway use normally ranges from about 10,000 to 32,000 liters (2600 to 8450 gallons). The tanks are usually cylindrical or have an elliptical cross-section, and are typically about 1.7 to 3 meters (5.6 to 10 feet) in "diameter" by 4.6 to 12 meters (15 to 40 feet) long. Railroad tanks and tank cars typically have volumes from about 8400 to 114,000 liters (2200 to 30,000 gallons). Inland barges are either 10.6 or 16 meters (35 or 52.5 feet) wide, are either 59.4 or 76 meters (195 or 250 feet) long, have depths in the range 2.7 to 4.3 meters (9 to 14 feet), and have capacities up to 2500 metric tons (about 2,500,000 liters or 660,000 gallons of a fluid with specific gravity of one).

Human strength is one of the major considerations in defining the liquid heads against which leaks can be plugged. The purpose of this program was to develop a prototype system for portable use by one man. This means that a single operator must be able to exert a force sufficient to hold a plug in place against the hydraulic pressure of the leak for perhaps 1/2 minute. The type of leak-plugging concept used in the prototype could be further developed for multi-man or mechanical operation, thus going beyond the strength limitations of a single man.

The fluid head exerted on a leak depends on the tank size, shape, and relative elevation of the hole. Figure 27 gives parametric values of fluid head for a range of tank sizes, orientations, and hole locations. For simplicity, cylindrical tanks with flat ends are used in this generalized representation. The tank shape is expressed as a geometric factor (e) equal to the tank length divided by the equivalent diameter. (Typical values of e for highway and railway tankers are 3 to 7.) Curves 3 through 6 of Fig. 27 represent what is expected to be more common situations encountered in tanker accidents. Curves 1 and 2 (Fig. 27) represent rather unusual cases, which would result in particularly high liquid heads (e.g., curve 1 assumes the tanker is standing on its end, with the tank completely full of liquid and the hole at the very bottom of the tank).

One of the very interesting conclusions that can be drawn from Fig. 27 is that most of the leak-plugging applications should involve fairly moderate liquid heads, e.g., less than about 2 meters (7 feet) for highway tank trucks, and less than about 3 meters (10 feet) for railway tank cars. The prototype leak-plugging system has been used successfully to plug 10-cm (4-inches) holes against a fluid head of 3.7 meters (12 feet) of water.

The force that a single operator must exert to hold a plug against the leaking fluid depends on the fluid head, the size of the hole, and the fluid density. Figure 28 shows parametrically the tradeoffs between these three variables for a constant operator force of 233 Newtons (50 lbf), which is estimated to be the maximum usable force that a single man can exert in a horizontal direction. This usable force was corroborated during this

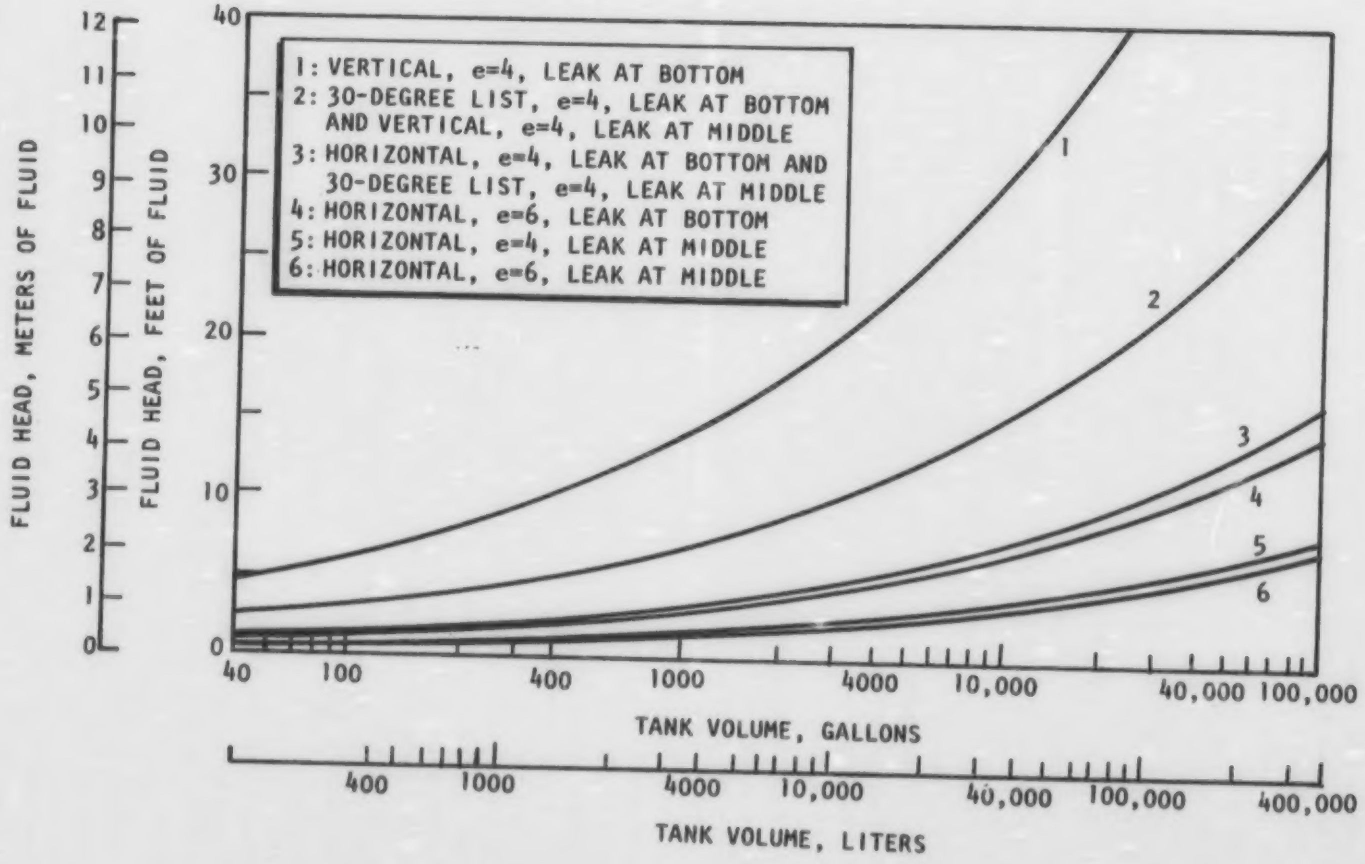

Figure 27. Maximum Fluid Head in Various Containers

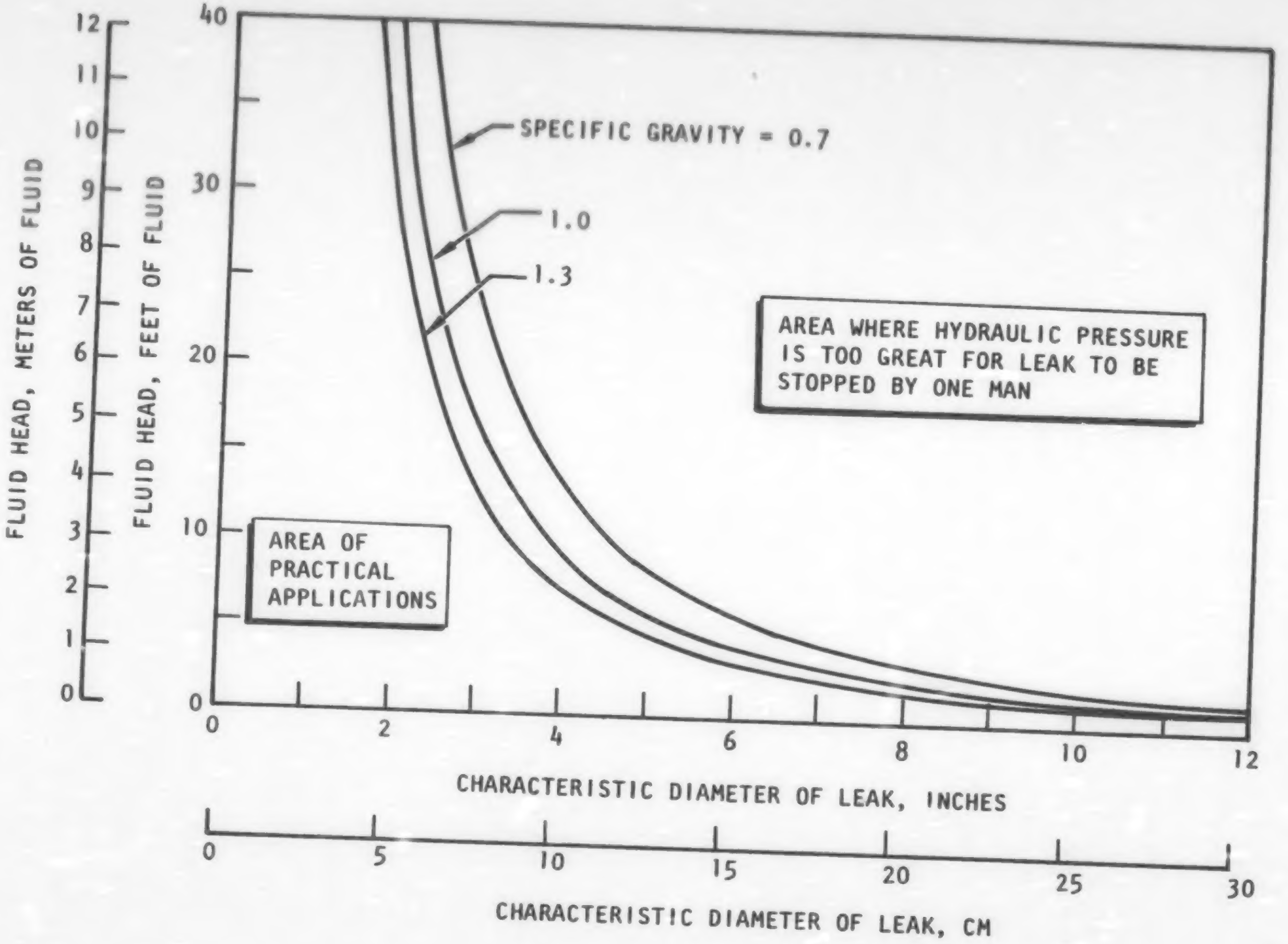

Figure 28. Envelope of Practical Fluid Head and Leak Sizes for One-Man Operation

program. It was found that with a fluid head of 3.7 meters (12 feet) of water, an operator could plug an 8-cm (3-inch) hole readily, a 9-cm (3-1/2-inch) hole with moderate difficulty, and a 10-cm (4-inch) hole only with maximum exertion. The leak equivalent diameter for a head of 3.7 meters (12 feet) and a specific gravity of 1.0 is about 9-cm (3.5 inches) from Fig. 28.

Figure 28 also can be used to evaluate the approximate relationship between leak size and head. For example (with a 0.7 specific gravity fluid), it would be roughly as easy to plug a 5.6-cm (2.2-inch) hole with 12 meters (13 feet) of head, or a 15-cm (6-inch) hole with 1.8 meters (6 feet) of head.

The second major consideration in defining the usable range of the leak-plugging system is the time of response. Obviously, a very large hole in a small container will result in a complete loss of the contents before corrective action can be taken. Therefore, there is an upper limit on hole size (as a function of container size, liquid head, and response time) which it is practical to consider. Efflux times can be calculated for any given container geometry and orientation, hole size and location, and type of liquid. An analysis was made, using the following assumptions:

a. Leak sizes may be specified by a single characteristic diameter.

b. Containers have a cross-sectional area that does not vary with liquid height and is specified by a characteristic diameter.

c. Leaks occur at the bottom of the vessel.

d. The effective container height divided by the characteristic diameter is a known value, (e), which is generally less than the actual container height divided by the actual diameter.

Figure 29 (taken from Ref. 3) shows results (curves A1 and A2) for the adverse case of a cylindrical container standing on end with the leak at the bottom of the container. Even under these unusual conditions, it would be practical to seal large leaks, e.g., 8 to 13 cm (3 to 5 inches), in tank trucks and tank cars. For the more usual types of leaks (tanks not upended vertically and holes not at the very bottom of the tank), the time for response and/or practical leak size to plug before substantial chemical loss occurred would be much higher.

15. Wide Temperature Tolerance. The supplier of the baseline foam components (Olin Corporation) recommends rather restrictive temperature limits for the foam components and Olin foam guns. Selected recommendations from this supplier are cited below:

a. Material cylinders should never be stored at temperatures below 21 C (70 F) or above 32 C (90 F).

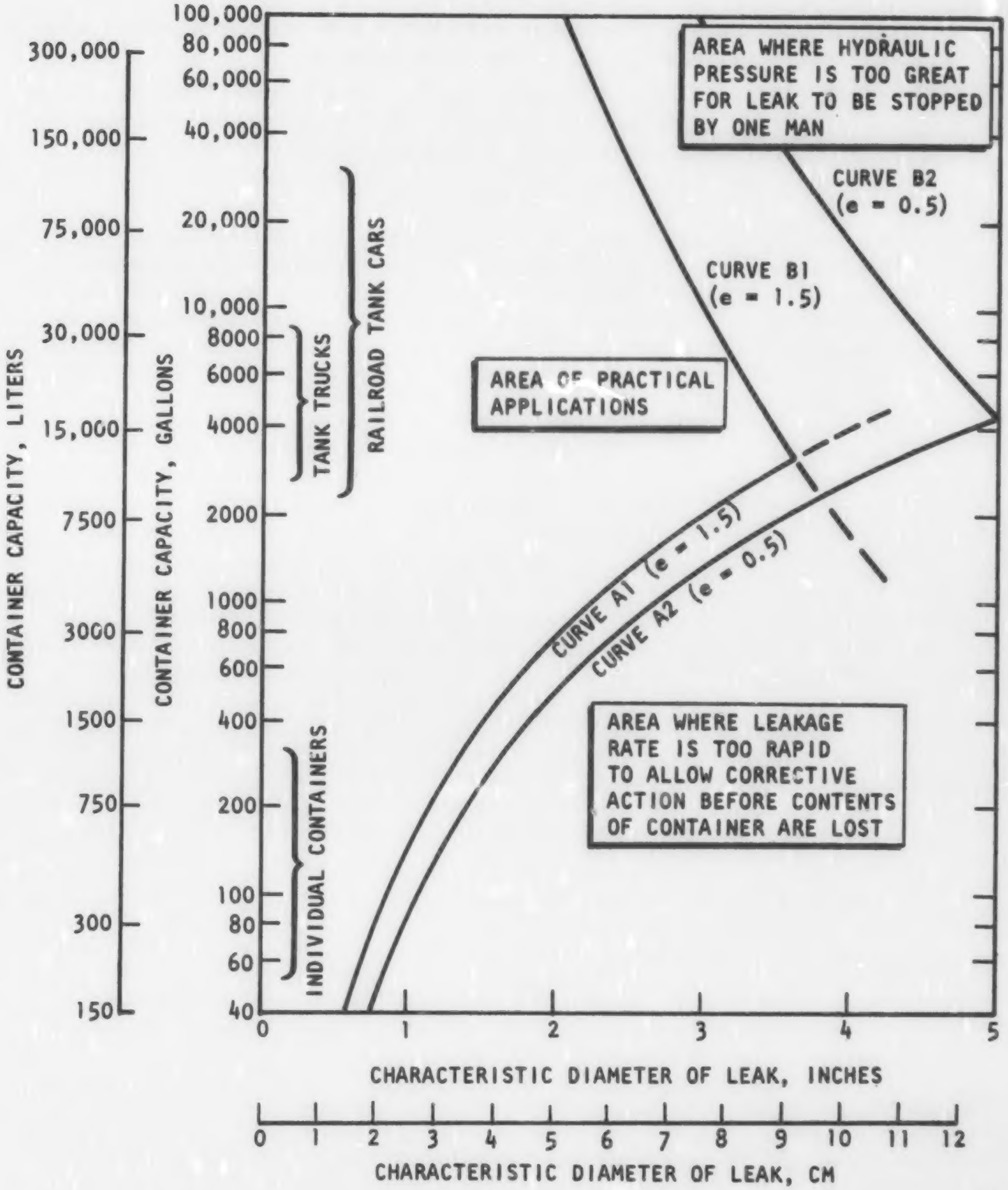

Figure 29. Envelope of Practical Applications for Sealing Leaks in Nonsubmerged Containers

b. For optimum operation, material temperatures in the cylinders should be above 24 C (75 F) and below 32 C (90 F).

c. These temperature ranges are critical as they can affect the ratio and reactivity of the foam systems.

d. Excessive direct heat should never be applied to any cylinder. In order to bring the chemicals contained in the cylinders up to operating temperatures, they should be placed in a warm environmental room, or box, for a period sufficient to allow a gradual warming of the chemicals.

Considerable effort was made during this program to extend the usable temperature range beyond the usual commercial practice. It was found that commercially available urethane foam delivery systems did not maintain the correct component mixture ratio at low temperatures because the flow control was maintained through pressure drop and the two components have large differences in temperature effect on viscosity. Development efforts during this program have eliminated this problem through introduction of an inert mixing gas. This development also permits elimination of a static mixer tube, thereby avoiding the high-pressure drop that is experienced in a static mixer when flowing very cold urethane foam components.

As a result of the development work, successful tests were made when the temperature of the foam, delivery equipment, and leaking fluid was as low as 7 C (44 F) and as high as 38 C (100 F). In addition, a successful foam expulsion test was made with the foam and hardware at about 18 C (65 F), then chilled in a 0 C (32 F) atmosphere for 3 minutes before firing. The latter test was made to approximate the operational situation in which the leak-plugging equipment was removed from a storage location at moderate temperatures and brought outside just prior to its use at winter temperatures. Additional tests are needed to more completely evaluate the temperature capabilities of the prototype system.

The following approximate guide is suggested, pending further evaluation: the prototype system with the baseline Olin No. 202-C1 urethane foam is usable when the foam and hardware have been stored between about 10 and 38 C (50 and 100 F). The system also can be used to plug leaks at much colder temperatures, down to at least 0 C (32 F), provided the system is not exposed to the colder temperatures for more than about 3 minutes before use.

IMPLEMENTATION PLAN

The prototype leak-plugging system described in this report has been developed to the point that it is now realistic to project practical field use of such a system. There are at least two major facets to consider in planning the future operational use of a leak-plugging system: motivational forces (i.e., what will motivate production development, manufacture, and purchase of the devices) and technical dimensions (such as exactly which device to use, where they will be deployed, who will use them, etc.). These major facets are discussed in this section.

Motivational Forces

Wide-scale operational use of such a leak-plugging system (or any other system that mitigates the potential effects of hazardous materials spills) will occur only if there is a clear need or requirement for transportation companies and/or emergency crews to purchase and deploy such equipment. A second requisite, before wide-scale operational use of such a system can be made, is for a manufacturing company to complete a production development project to bring the present prototype to a version suitable for economical mass production. This production development will occur only if there is a good potential market for the product.

It is expected that legislation or regulations will be required to motivate implementation. These may be new requirements or they may be developed within the framework of existing regulations (e.g., if the penalties for chemical spills become great enough to motivate purchases of devices to mitigate the effects of potential spills).

Technical Dimensions

Large tanks containing hazardous chemicals can be divided into categories, e.g., (1) highway trucks and trailers, (2) railroad cars, (3) barges and other watercraft, (4) stationary storage tanks and loading facilities, and (5) pipelines.

In each of the first four categories, a leak-plugging system could be carried on the transportation vehicle or at the loading site. The equipment then would be readily available at the earliest possible time to plug a leak. In some accidents, the equipment and/or personnel at the site of the leak may be incapacitated by the same accident that caused the leak, e.g., a case of a damaged tank truck that suffered an accident in which the driver was injured or the leak-plugging equipment was damaged. From this point of view, the best (or a backup) storage location for leak-plugging equipment would be a centrally located emergency center such as a fire department or equivalent which has trained personnel who can respond immediately to a call for assistance. The disadvantage to a more centrally located deployment is the time delay involved before the leak can be plugged.

A combination of on-site and centeral deployment may be the best overall plan. The following are possible combinations:

1. Simple passive equipment on each tank truck
2. The basic leak-plugging system on some tank trucks (with higher hazard potential), on trains carrying hazardous chemicals, at hazardous chemical handling facilities, and at major fire department/emergency crew facilities

3. Additional (e.g., larger, varied) leak-plugging plus other spill response devices deployed at selected fire department/emergency crew locations, with EPA and Coast Guard response teams, and (eventually) with commercial spill response companies

For example, the passive solid rubber cone plugs constructed of silicone rubber (described in Section V) and mounted on the end of a collapsible pole could be used effectively to partially seal holes in tanks by simply pushing them into the holes. Such devices are very inexpensive and easy to use. A suit of protective clothing also would be provided. These devices would be used by the vehicle operator to administer "first aid" until an emergency crew could arrive at the scene of the accident with a basic leak-plugging system (similar to the prototypes described in Section VI).

Additional work is needed to prepare the way for deployment and wide-scale operational use of the EPA leak-plugging system, through establishing the basis for two essential subsequent actions: (1) legislation or regulations that establish a realistic need for the type of environmental protection afforded by a leak-plugging device, and (2) production development by interested manufacturing companies.

An evaluation should be made of data already collected on past hazardous materials spills to estimate the potential benefits that could have been realized if various leak-plugging systems had been available. Three stages of deployment (with different degrees of proximity to an accident site) should be considered: (1) system is on the transportation vehicle or chemical handling site, (2) system is available at the nearest city fire department, and (3) system is available at a central location within the EPA region in which the accident occurred. Estimates then should be made of the costs to deploy leak-plugging equipment to various degrees (including the three levels of deployment mentioned above). The potential impacts of these costs should be estimated, including such questions as who would pay for the emergency repair equipment, the degree to which these would impact shipping and chemical costs, etc.

Detailed discussions should be held with individuals who can accurately represent the positions and attitudes of various organizations that would be affected by and involved in the use of leak-plugging devices. These organizations might include EPA National Contingency Plan personnel, Coast Guard and other DOT personnel, municipal fire departments, trucking companies, railroad companies, barge companies, unions, chemical companies, and various trade associations. The purpose of these discussions would be to obtain information and options that will permit further definition of the detailed requirements to be imposed on use of the system, and an assessment of the degree of cooperation or resistance to deployment and use of leak-plugging devices either on transportation elements or at emergency crew locations. It is important to determine practical expectations for both deployment locations and type of personnel who will use the devices.

After completion of the portion of this task dealing with assessing user acceptance, and incorporation of any necessary changes to promote operator safety and confidence, there should be a modest effort to field test and demonstrate one or more leak-plugging systems devices with personnel from transportation and emergency organizations.

Based on the estimates of potential benefits and costs, personnel requirements, and the field testing (with various combinations of leak-plugging equipment deployed in any or all of three levels), trade-off studies should be made to determine when and in what way operational use of the EPA leak-plugging equipment should be made. Consideration should be given to various requirements and constraints (e.g., technical, economic, legal, human, and logistic).

SECTION VII

REFERENCES

1. Wilder, Ira, and J. Lafornara, Control of Hazardous Materials Spills in the Water Environment: An Overview, presented before the Division Water, Air and Waste Chemistry, American Chemical Society, Washington, D.C., September 1971.
2. Mitchell, R. C., M. Kirsch, C. L. Hamermesh, and J. E. Sinor, "Methods for Plugging Leaking Chemical Containers," Proceedings of the 1972 National Conference on Control of Hazardous Material Spills, Houston, Texas, 21-23 March 1972.
3. Mitchell, R. C., C. L. Hamermesh, and J. V. Lecce, Feasibility of Plastic Foam Plugs for Sealing Leaking Chemical Containers, Report EPA-R2-73-251, Rocketdyne Division, Rockwell International, Canoga Park, California, for the U.S. Environmental Protection Agency, Contract No. 68-01-0106, May 1973.
4. "Environmental Protection Agency (40 CFR Part 116) Designation of Hazardous Substances, Notice of Proposed Rule Making," Federal Register, Vol. 40, No. 250, 30 December 1975.
5. R-9604, Plugging Large Leaks in Ruptured Containers, 16 mm color/sound film, Rocketdyne Division, Rockwell International, Canoga Park, California, February 1975.

SECTION VIII

PUBLICATIONS AND PATENTS

Mitchell, R. C., J. J. Vrolyk, R. W. Melvold, and I. Wilder, "System for Plugging Leaks From Ruptured Containers," *Proceedings of the 1974 National Conference on Control of Hazardous Material Spills*, San Francisco, California, 25-28 August, 1974.

Mitchell, R. C., J. J. Vrolyk, R. W. Melvold, and I. Wilder, "Prototype System for Plugging Leaks in Ruptured Containers," *Proceedings of the 1976 National Conference on Control of Hazardous Material Spills*, New Orleans, Louisiana, 25-28 April 1976.

SECTION IX

APPENDICES

A. Leak-Plugging System Design Drawings and Parts List . . . . . .

B. Refilling the Foam Delivery System . . . .

APPENDIX A

LEAK-PLUGGING SYSTEM DESIGN DRAWINGS AND PARTS LIST

Reduced sections of the master design drawing* showing details of the leak-plugging system appears in Fig.A-1 through A-6, followed by the parts list in Table A-1. The part numbers in the parts list also appear in small circles next to the corresponding components in the drawings. The parts list gives the item function (or name), the supplier, supplier's part number, size and type connection or interface, the operating pressure, and design and procurement comments.

The numbers appearing in parentheses on the design drawings are the inch dimensions converted to centimeters. Because suppliers do not identify components in metric terms, metric conversion was not rendered on the parts list.

The delivered prototype systems discussed in this report involve two different delivery system sizes. The size refers to the tandem cylinder size: The large cylinder has a total displacement (both compartments) of 614.0 cc (34.47 in.^{3}) and the small one has 345.5 cc (21.08 in.^{3}). Also discussed are two different means of actuation--penumatic and mechanical. Actually constructed and appearing in the various photographs are: (1) the large tandem cylinder with the pneumatic actuation, and (2) the small tandem cylinder with mechanical actuation. The other two possible combinations can be built, if desired.

The drawings show a combination of the pneumatic actuation with the small tandem cylinder. Only small changes in tubing length are required to convert from a small to a large tandem cylinder; these changes are called out in the notes at the end of the parts list.

The parts list refers to the parts of the pneumatically actuated system with the large tandem cylinder as built. This is a baseline to which all other changes (to obtain other combinations) refer. To change from pneumatic to mechanical actuation, the instructions in Note 8 should be followed. To change from a large to a small tandem cylinder, the instructions Notes 2 and 5 should be followed.

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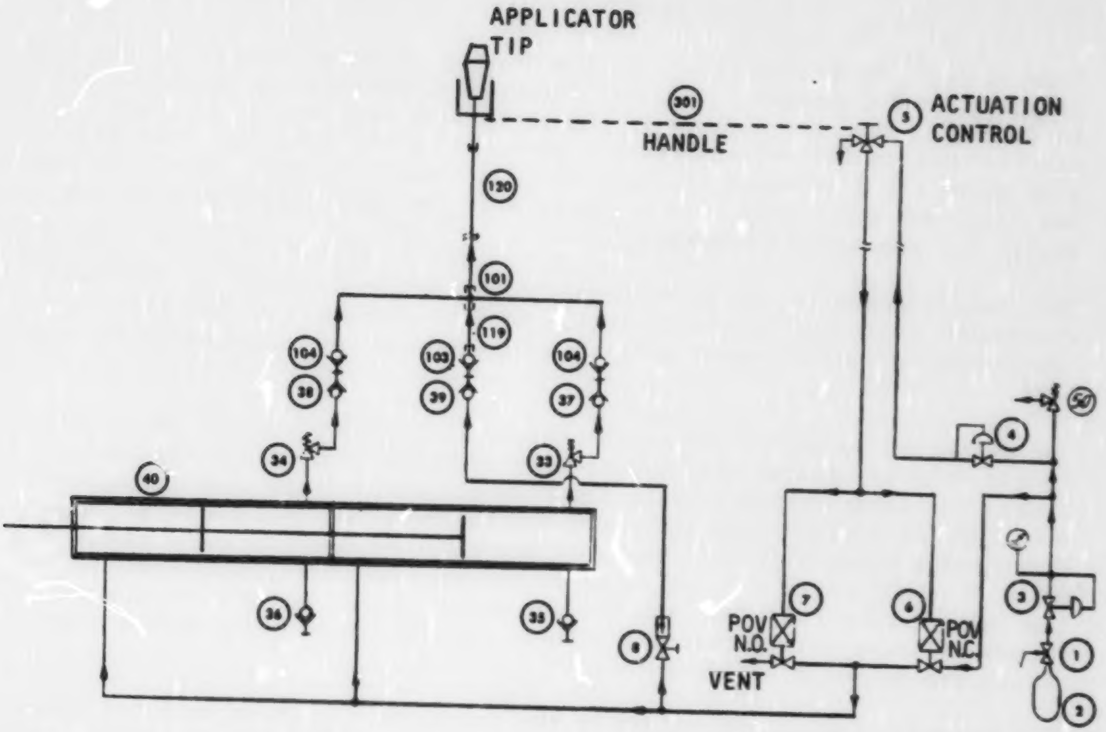
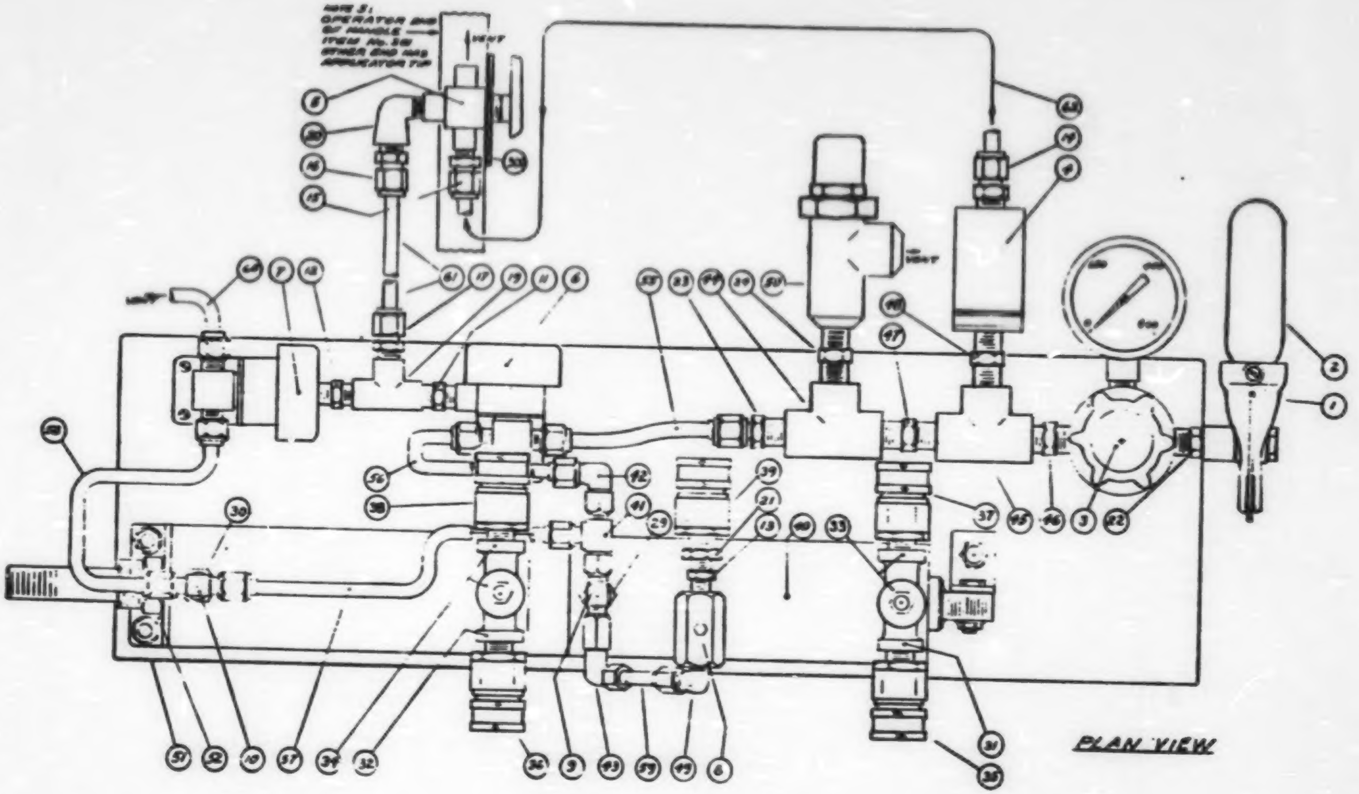
*Completed, full-size drawings are available at the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Edison, New Jersey, 08817.


APPLICATOR TIP
301
HANDLE
5
ACTUATION CONTROL
120
101
119
104
103
104
38
39
37
34
33
40
50
4
36
35
8
7
6
POV N.O.
POV N.C.
VENT
3
1
2

PIPING SCHEMATIC

Circled numbers refer to component description in the Parts List

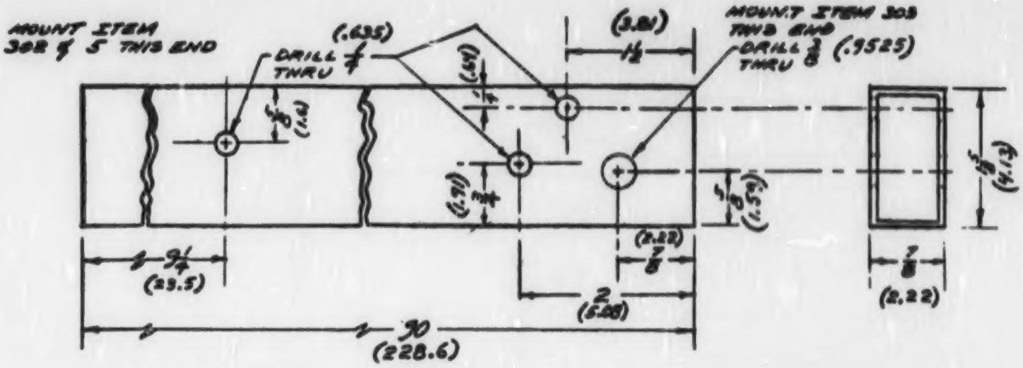
Figure A-1. Schematic Diagram of Pneumatically Operated Prototype Leak Plugging System


NOTE 3:
OPERATOR END
OF HANDLE
ITEM No. 58
OTHER END HAS
APPLICATOR TIP
VENT
VENT
PLAN VIEW

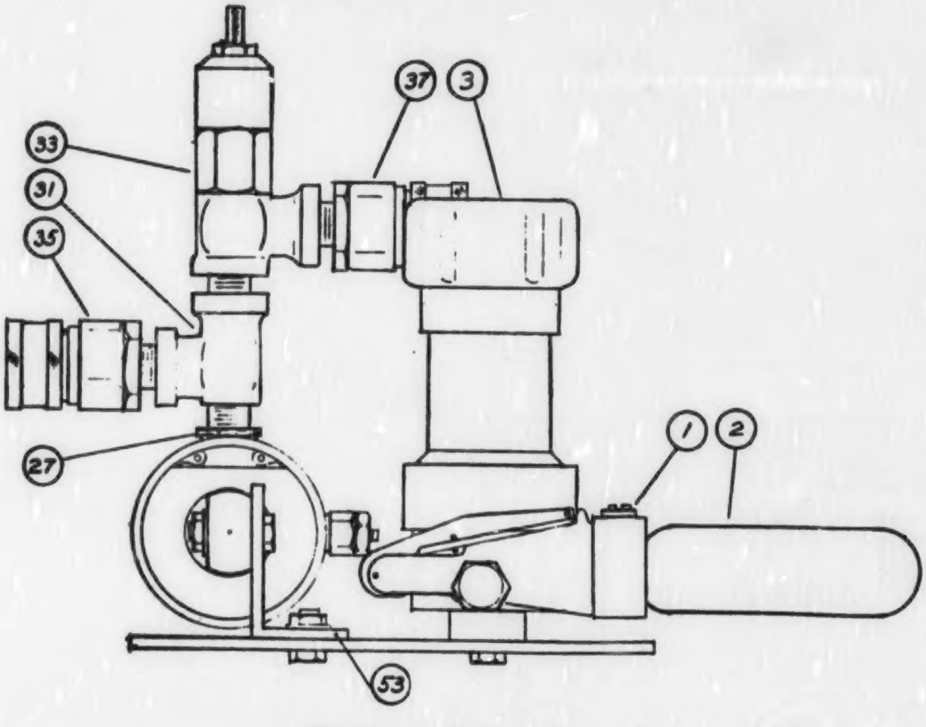
DELIVERY SYSTEM ASSEMBLY

NOTE 6: CIRCLED NUMBERS ARE ITEM NUMBERS IN PARTS LIST

Figure A-2. Plan View of Pneumatically Actuated Prototype Delivery System (scale is approximately 1/2 actual)

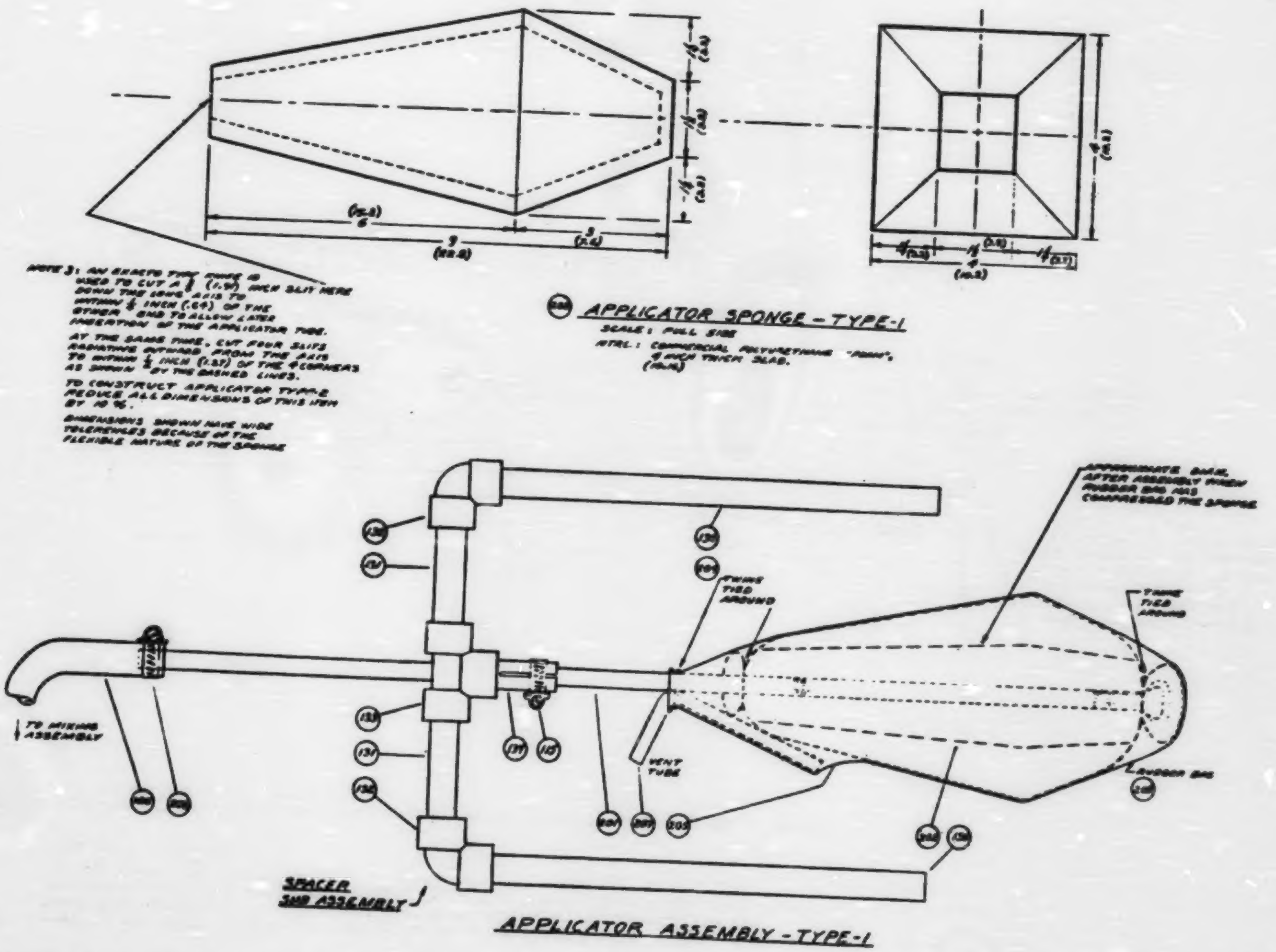

MOUNT ITEM 302 & 5 THIS END
(.635)
DRILL 1/4 THRU
5/8 (1.6)
1/4 (.64)
(3.81)
1 1/2
MOUNT ITEM 303 THIS END
DRILL 3/8 THRU (.9525)
(1.91) 3/4
5/8 (1.59)
1 5/8 (4.13)
9 1/4 (23.5)
(2.22) 7/8
2 (5.08)
90 (228.6)
7/8 (2.22)

HANDLE
ITEM NO. 301
NOT TO SCALE


37
3
33
31
35
27
1
2
53

END VIEW

Figure A-3. End View of Pneumatically Actuated Prototype Delivery System (scale is approximately 1/2 actual) and Detail Drawing of Applicator Handle

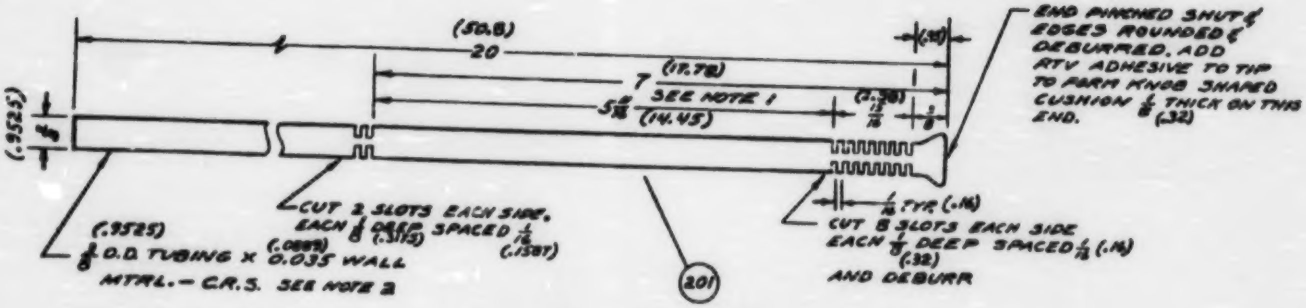


NOTE 3: AN EXACTO TYPE KNIFE IS USED TO CUT A ¾ (1.9) INCH SLIT HERE DOWN THE LONG AXIS TO WITHIN ¼ INCH (.64) OF THE OTHER END TO ALLOW LATER INSERTION OF THE APPLICATOR TUBE.
AT THE SAME TIME, CUT FOUR SLITS RADIATING OUTWARD FROM THE AXIS TO WITHIN ½ INCH (1.27) OF THE 4 CORNERS AS SHOWN BY THE DASHED LINES.
TO CONSTRUCT APPLICATOR TYPE-2 REDUCE ALL DIMENSIONS OF THIS ITEM BY 10 %.
DIMENSIONS SHOWN HAVE WIDE TOLERANCES BECAUSE OF THE FLEXIBLE NATURE OF THE SPONGE
APPLICATOR SPONGE - TYPE-1
SCALE: FULL SIZE
MTRL.: COMMERCIAL POLYURETHANE "FOAM", 4 INCH THICK SLAB.
APPROXIMATE SHAPE AFTER ASSEMBLY WHEN RUBBER BAG HAS COMPRESSED THE SPONGE
TWINE TIED AROUND
TWINE TIED AROUND
RUBBER BAG
VENT TUBE
TO MIXING ASSEMBLY
SPACER SUB ASSEMBLY
131
131
117
115
205
APPLICATOR ASSEMBLY - TYPE-1

Figure A-4. Applicator Assembly (scale is approximately 1/3 actual) and Applicator Tip Detail Drawing

NOTE 1 APPLICATOR TUBE TYPE-2 IS IDENTICAL TO APPLICATOR TUBE TYPE-1 EXCEPT THAT THE DIMENSIONS LOCATING THE TWO SLOTS WITH RESPECT TO THE PINCHED END ARE REDUCED BY $\frac{1}{2}$ INCH (1.27) EACH FROM 7 (17.78) AND $5\frac{11}{16}$ (14.45) FOR TYPE-1 TO $6\frac{1}{2}$ (16.15) AND $5\frac{3}{16}$ (13.18) FOR TYPE-2.

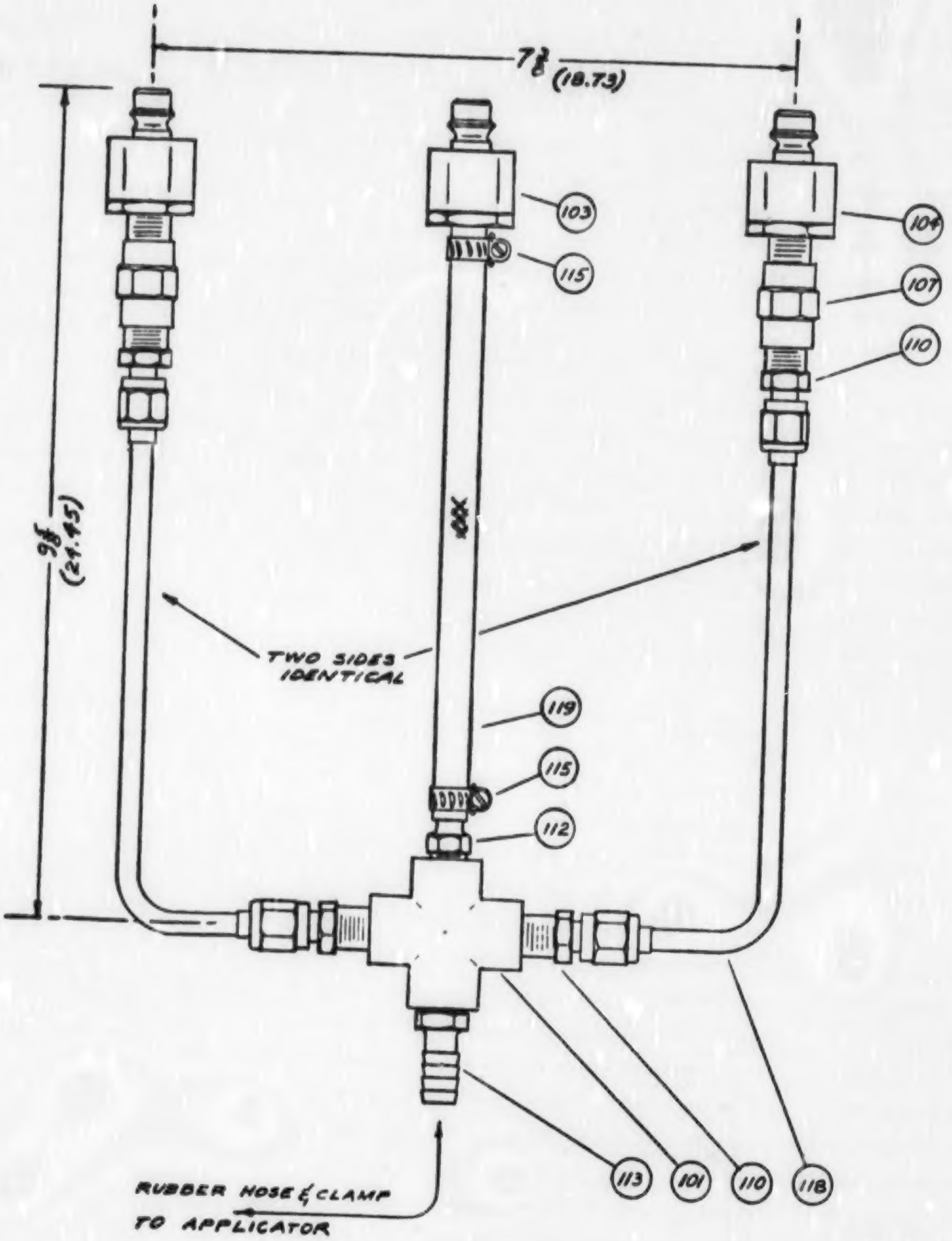
NOTE 2 TUBE MATERIAL IS NOT CRITICAL EXCEPT THAT RIGIDITY SHOULD BE APPROX. THE SAME AS THAT SHOWN.


(50.8)
20
7 (17.78)
SEE NOTE 1
$5\frac{11}{16}$ (14.45)
(2.38)
$\frac{15}{16}$
$\frac{1}{8}$
(.32)
(.9525)
$\frac{3}{8}$
END PINCHED SHUT & EDGES ROUNDED & DEBURRED. ADD RTV ADHESIVE TO TIP TO FORM KNOB SHAPED CUSHION $\frac{1}{8}$ (.32) THICK ON THIS END.
CUT 2 SLOTS EACH SIDE. EACH $\frac{1}{8}$ (.3175) DEEP SPACED $\frac{1}{16}$ (.1587)
(.9525) $\frac{3}{8}$ O.D. TUBING x (.0889) 0.035 WALL
MTRL.— C.R.S. SEE NOTE 2
201
$\frac{1}{16}$ TYP. (.16)
CUT 8 SLOTS EACH SIDE EACH $\frac{1}{8}$ (.32) DEEP SPACED $\frac{1}{16}$ (.16)
AND DEBURR

NOTE 4: TOLERCES ON SLOT LOCATIONS ARE WIDE AND SLOT WIDTH DIMENSIONS ARE MINIMUMS ONLY.

APPLICATOR TUBE - TYPE-1

Figure A-5. Applicator Tube Detail Drawing (scale is approximately 1/2 actual)


7⅜ (18.73)
9⅝ (24.45)
103
104
115
107
110
TWO SIDES IDENTICAL
119
115
112
113
101
110
118
RUBBER HOSE & CLAMP TO APPLICATOR

MIXING ASSEMBLY

Figure A-6. Applicator Mixing Assembly Drawing (scale is approximately 1/2 actual)

TABLE A-1. PROTOTYPE PARTS LIST

NAME: LARGE DELIVERY SYSTEM

Item No.	Item Function	Manufacturer and Part Number	Size, Inches, and Type of Connection	Operating Pressure, psi	Miscellaneous Data
1	Inflator With Jerk Tab	Aeromarine Manufacturing, Del Ray Beach, Florida A-145 (PN-3165-2)	Sparklett Devices, Inc. St. Louis, No. 3165	1200	Drill out exit fitting 1/8-inch bore
2	Cylinder, Carbon Dioxide	Sparklett Devices, Inc., St. Louis, Missouri No. 240 MIL C-25369B Type I	CO_2 Content: 26 gms net	1200	Expendable
3	Pressure Regulator	Veriflo Corp., 41300483, IR402-B-250 G	1/4 NPT		With 0 to 600-psi gage
4	Pressure Regulator	C. A. Morgen, Teglen Engineering, El Monte, California, R37-200-N70A	1/4 NPT	200 to	Pre-set at factory to 70 psig
5	3-Way Ball Valve	Whitey Co., Oakland, California, B-42XF2	1/8 NPT	70	Main operation valve. Located on handle.
6	Valve and Actuator	Whitey Co., Oakland, California, B-9254	1/8 NPT (Actuation) x 1/4 Swagelok	250	Normally closed
7	Valve and Actuator	Whitey Co., Oakland, California, B-9354	1/(NPT (Actuation) x 1/4 Swagelok	250	Normally closed
8	Check/Needle-Valve	DELTROL, Bellwood, Illinois, CPN-10-B, Size 10	1/8 NPT	250	Set at 30 cph with GN_2 at 230 psig
9	Special Tee	Airdrome Parts Co., Long Beach, California AN-825 S.S.	1/4 AN x 1/4 AN x 1/8 NPT on the side	250	
10	Special Tee	Airdrome Parts Co., Long Beach, California AN-825 S.S.	1/4 AN x 1/4 AN x 1/8 NPT on the side	250	
11	Pipe Nipple	Airdrome Parts Co., Long Beach, California AN-911-1 S.S.	1/8 NPT x 1/8 NPT	70	Common pipe type can be substituted
12	Pipe Nipple	Airdrome Parts Co., Long Beach, California AN-911-1 S.S.	1/8 NPT x 1/8 NPT	70	Common pipe type can be substituted
13	Pipe Nipple	Airdrome Parts Co., Long Beach, California AN-911-1 S.S.	1/8 NPT x 1/8 NPT	250	Must hold 250-psi gas pressure
14	Adapter Fitting	Swagelok:Ventura Valve and Fitting Co., Newberry Park, California, NY-400-1-4 (Nylon)	1/4 NPT x 1/4 Swagelok	70	
15	Adapter Fitting	Swagelok: Ventura Valve and Fitting Co., Newberry Park, California, NY-400-1-2 (Nylon)	1/8 NPT x 1/4 Swagelok	70	
16	Adapter Fitting	Swagelok: Ventura Valve and Fitting Co., Newberry Park, California, NY-400-1-2 (Nylon)	1/8 NPT x 1/4 Swagelok	70	
17	Adapter Fitting	Swagelok: Ventura Valve and Fitting Co., Newberry Park, California, NY-400-1-2 (Nylon)	1/8 NPT x 1/4 Swagelok	70	
18					
19	Tee	Airdrome Parts Co., Long Beach, California AN-917-1 S.S.	1/8 x 1/8 x 1/8 NPT Female	70	Common pipe type can be substituted
20	Elbow	Airdrome Parts Co., Long Beach, California AN-914-2 S.S.	1/4 NPT Street-L	70	Common pipe type can be substituted
21	Bushing	Airdrome Parts Co., Long Beach, California AN-912-1 S.S.	1/8 x 1/4 NPT	250	Required to withstand 300-psig gas
22	Adapter Fitting	Airdrome Parts Co., Long Beach, California AN-816-4-4 S.S.	1/4 NPT to 1/4 AN	1500	Use O-ring, MS28778-4, Compound N507-9
23	Adapter Fitting	Airdrome Parts Co., Long Beach, California AN-816-4-4 S.S.	1/4 NPT to 1/4 AN	1500	
24	Nipple	Airdrome Parts Co., Long Beach, California AN-911-2 S.S.	1/4 x 1/4 NPT	250	Identical to No. 46, 47, and 48
27	Bushing	Airdrome Parts Co., Long Beach, California AN-912-2 S.S.	3/8 x 1/4 NPT	250	(see Note 2) Used for large tandem cylinder only
28	Bushing	Airdrome Parts Co., Long Beach, California AN-912-2 S.S.	3/8 x 1/4 NPT	250	Used for large tandem cylinder only
29	Bushing	Airdrome Parts Co., Long Beach, California AN-912-1	1/4 x 1/8 NPT	250	If large cylinder is used, specify 3/8 x 1/8
30	Bushing	Airdrome Parts Co., Long Beach, California AN-912-1	1/4 x 1/8 NPT	250	If large cylinder is used, specify 3/8 x 1/8 (see Note 2)
31	Male Run Tee	Cajon: Ventura Valve Fitting Co., Newbury Park, California, Brass B-4-ST	1/4 NPT (male run)	250	
32	Male Run Tee	Cajon: Ventura Valve Fitting Co., Newbury Park, California, Brass B-4-ST	1/4 NPT (male run)	250	
33	Pressure Relief Valve	Hoke, Inc., Cresskill, New Jersey, 6514L4B Adjustable with Teflon seat	1/4 NPT	250	Set at 120 psig (see Note 1)
34	Pressure Relief Valve	Hoke, Inc., Cresskill, New Jersey, 6514L4B Adjustable with Teflon seat	1/4 NPT	250	Set at 120 psig (sce Note 1)
35	Quick Disconnect Valve Coupler	Haskell Engineering Co., Burbank, California VHC 4-4 MMV	Male 1/4 NPT	250	Refill port for polyole
36	Quick Disconnect Valve Coupler	Haskell Engineering Co., Burbank, California VHC 4-4 MMV	Male 1/4 NPT	250	Refill port for Isocyanate
37	Quick Disconnect Valve Coupler	Haskell Engineering Co., Burbank, California VHC 4-4 MMV	Male 1/4 NPT	250	Discharge port for polyole
38	Quick Disconnect Valve Coupler	Haskell Engineering Co., Burbank, California VHC 4-4 MMV	Male 1/4 NPT	250	Discharge port for Isocyanate
39	Quick Disconnect Valve Coupler	Haskell Engineering Co., Burbank, California VHC 4-4 F (MV-2)	Female 1/4 NPT	250	Discharge port for mixing gas

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TABLE A-1. (Continued)

NAME: LARGE DELIVERY SYSTEM

Item No.	Item Function	Manufacturer and Part Number	Size, Inches, and Type of Connection	Operating Pressure psi	Miscellaneous Data
40	Tandem Cylinder	Allenair Corporation, Mineola, New York, Type ET-BC-HTP	2-1/2 x 4, large 2 x 3, small	250	See Note 5
41	B-Nut Tee	Parker-Hannifin Corporation, Cleveland, Ohio 4-R6BX S.S.	B-Nut, Run Tee, 1/4 AN	250	
42	B-Nut Elbow	Parker-Hannifin Corporation, Cleveland, Ohio AA-67028-4K S.S.	B-Nut El, 90-degree 1/4 AN	250	
43	B-Nut Elbow	Parker-Hannifin Corporation, Cleveland, Ohio AA-67028-4K S.S.	B-Nut El, 90-degree 1/4 AN	250	
44	Pipe Tee	Airdrome Parts Co., Long Beach, California AN-917-2 S.S.	1/4 NPT, Tee	250	
45	Pipe Tee	Airdrome Parts Co., Long Beach, California AN-917-2 S.S.	1/4 NPT, Tee	250	
46	Nipple	Airdrome Parts Co., Long Beach, California AN-911-2 S.S.	1/4 x 1/4 NPT	250	
47	Nipple	Airdrome Parts Co., Long Beach, California AN-911-2 S.S.	1/4 x 1/4 NPT	250	
48	Nipple	Airdrome Parts Co., Long Beach, California AN-911-2 S.S.	1/4 x 1/4 NPT	250	
49	Special Elbow	Airdrome Parts Co., Long Beach, California AN-822-4 MS-20822-£J	1/4 AN x 1/8 NPT El	250	
50	Pressure Relief Valve	Teledyne Republic, Cleveland, Ohio R-4 6278-4-1/4-28	1/4 NPT, 250 psi maximum	250	Set at 250 psi which is maximum
51	Base Plate	Constructed from 1/8-inch aluminum sheet			See drawings for this part
52	Bracket Shaft End	Constructed from 1/8-inch aluminum sheet	As per Note 6		See drawings for this part
53	Bracket Closed End	Constructed from 1/8-inch aluminum sheet	As per Note 6		See drawings for this part
54	Cylinder Support Nut	Material is part of purchased tandem cylinder	Modify as per Note 7 Part of Item 40		Two required
55	Gas Supply Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
56	Gas Supply Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
57	Gas Supply Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
58	Gas Vent Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
59	Mixing Gas Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
60	Vent Tube	Constructed from copper tubing	1/4-diameter, 0.035 wall		Two required
61	Actuation Gas Tubing	Cadillac Plastics Co., North Hollywood, California No. 0112 polypropylene tubing	1/4 diameter x 10 feet long		
62	Actuation Gas Tubing	Cadillac Plastics Co., North Hollywood, California No. 0112 polypropylene tubing	1/4 diameter x 10 feet long		
101	Pipe Cross	Airdrome Parts Co., Long Beach, California AN-918 S.S.	1/4 NPT		One required
103	Quick Disconnect Valve Nipple	Haskell Engineering Co., Burbank, California VHN 4-4 H (MV-2)	Male 1/4 NPT	50	One required
104	Quick Disconnect Valve Nipple	Haskell Engineering Co., Burbank, California VHN 4-4 MNV	Male 1/4 NPT	50	Two required
107	Pipe Coupling	Commercial Hardware Supplier, Brass	1/4 NPT		Two required
110	Nipple, Pipe, and Tube	Airdrome Parts Co., Long Beach, California AN 816-4-4 S.S.	1/4 NPT x 1/4 AN		Two required
112	Hose Adapter	Ryan-Herco Products Co., Burbank, California 0700-162 polypropylene	1/4 NPT to 3/8 hose	50	One required
113	Hose adapter	Ryan-Herco Products Co., Burbank, California 0700-162 polypropylene	1/4 NPT x 1/2 hose	50	One required
115	Hose Clamp	Ryan-Herco Products Co., Burbank, California, S.S.	1/4 0750-004	50	Two required
118	Delivery Tube Assembly	Constructed from metal tubing S.S.	1/4 x 0.035 wall	50	Constructed from tubing, B-nuts, and rings, two required
119	Gas Delivery Tube	Ryan-Herco Products Co., Burbank, California No. 0030-071, Tygon Innerbraided Tubing		50	Approximately 7 inches long
120	Long Delivery Tube	Van Water and Rogers, San Francisco, California Rubber tubing	3/8 ID x 5/8 OD	50	100 inches long
130	Spacer, Longitudinal	Ryan-Herco Products Co., Burbank, California 1/4-diameter, schedule 80 pipe	Material PVC		8-3/4 inches long, two required
131	Spacer, Radial	Ryan-Herco Products Co., Burbank, California 1/4-diameter, schedule 80 pipe	Material PVC		5-3/4 inches long, two required
132	Spacer Elbow	Ryan-Herco Products Co., Burbank, California No. 3806-002 1/4-inch elbow	Material PVC		Two required
133	Spacer Tee	Ryan-Herco Products Co., Burbank, California No. 3801-002 1/4-inch tee	Material PVC		One required
134	Tube Clamp	Ryan-Herco Products Co., Burbank, California 1/4-inch diameter, schedule 80 pipe	Modify as per Note 3		Cut to length (1-1/2 inches), one required

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TABLE A-1. Continued)

NAME: LARGE DELIVERY SYSTEM

Item No.	Item Function	Manufacturer and Part Number	Size, Inches and Type of Connection	Operating Pressure, psi	Miscellaneous Data
201	Applicator Main Delivery Tube	Tube Sales, Los Angeles, California Metal tubing S. S.	3/8 x 0.035 wall tubing		Drilled as per drawing
202	Reticulated Foam	Commercial Hardware Dealer, Made from polyurethane foam mattress material			
203	Sealant (silicone)	General Electric, RTV-106 (white) RTV-102 (red)			
204	Twine	Nylon tie cord, waxed			
205	Rubber Bag (membrane)	Sherwood Medical Inc., Pioneer Rubber Co., Division, Tiffin Road, Willard, Ohio, K-1225-N			Used as required in assembly
207	Vent Tube	Cadillac Plastics, Detroit, Michigan Cellulose acetate butyrate tubing	5/16 OD x 1/4 ID		Approximately 5-inch length per applicator
208	Hose Clamp	Ryan-Herco Products Co., Burbank, California, S.S.	5/8 inch		Two required
301	Handle	Tube Sales, Los Angeles, California Aluminum box beam	7/8 x 1-5/8 x 7-1/2 feet long		
302	Valve Bracket	Standard Steel, washer			
303	Applicator Clamp	Fisher Scientific, No. 1540	2-1/8 OD 1/2 ID x 1/8 thick		

NOTE 1:

The adjustable pressure relief valves called out as items 33 and 34 are mounted on the small tandem cylinder delivery system. The large system has the Teledyne pressure relief valve identical to item 50 in place of items 33 and 34. However, for new construction the valve described for items 33 and 34 is preferred for this use and is recommended for new construction instead of item 50.

NOTE 2:

Part No. 27, 28, 29, and 30 are used only to adapt the large cylinder which has 3/8-inch pipe ports to the other plumbing above these ports. The small cylinder has 1/4-inch pipe ports.

The drawing of the mixing assembly has one dimensional change that is of basic importance when changing from a small to large tandem cylinder: i.e., the 7-3/8-inch (18.73-cm) dimension between the two outer quick disconnects should be changed to a larger dimension corresponding to the distance between the two outlet ports on the large tandem cylinder. (see Note 5)

NOTE 3:

Spacer Subassembly Construction

1. Cut required number and lengths of schedule 80 PVC pipe as specified for Part No. 130, 131 and 134.
2. Cement Part No. 134 into Part No. 133 as shown on the assembly drawing using cement described as follows:

   PVC Solvent Cement PIP205
   Permalite Plastic Corporation
   Newport Beach, California
3. After cement has set, drill along axis of tube (Part No. 134) 25/64-inch diameter and continue drilling through the back of the tee (Part No. 133).
4. Cut slots 1 inch deep, one on each side of Part No. 134 by making a hacksaw cut across the tube end as shown in assembly drawing.
5. Slip hose clamp (Part No. [illegible]) over the slotted end of Part No. 134.
6. Slip the applicator tube through the hole in the tee and tighten the hose clamp to result in the arrangement shown in the Applicator Assembly drawing.

NOTE 4:

S.S. stands for stainless steel

NOTE 5:

Item 40, the tandem cylinder, is changed to the following designation to construct a small delivery system:

Tandem Cylinder
Allenair Corporation
Mineola, New York
Type ET-BC-HTP 2 x 3

Large and Small Tandem Cylinders

The as-delivered hardware is equipped with a small cylinder for the mechanically actuated model which is mounted on a backpack rack. A cylinder having twice the delivered volume capability of the small one is incorporated into the pneumatically operated unit. It is this latter unit which is described in detail in drawing AP-75-002 and the accompanying parts lits. The drawing is different from the as-built pneumatic system in only one way; the tandem cylinder depicted is the small size rather than the large size to illustrate the very close similarity between the designs when this simple subsituation is made.

CAUTION: Note that when the cylinder size is changed, the distance between the outer tubes of the mixing assembly (7-3/8 inches in the subject drawing) must also be changed to match the distance between the exit holes in the tandem cylinder. Thus, mixing subassemblies are not interchangeable between large and small cylinders. Ultimately, this should present no problem in a production item, but is presented as a precaution until this is changed.

Calculated Volume Displacement during one stroke of the Tandem Cylinder.

Size	Manufacturing Designation Number	Cylinder With Rod Extending Through		Cylinder Without Rod Extending Through		Totals	
		cc	cu in.	cc	cu in.	cc	cc in.
Small	ET-BC-HTP 2 x 3	139.5	8.51	206	12.57	345.5	21.08
Large	ET-BC-HTP 2-1/2 x 4	292.4	17.84	321.6	19.63	614	37.47

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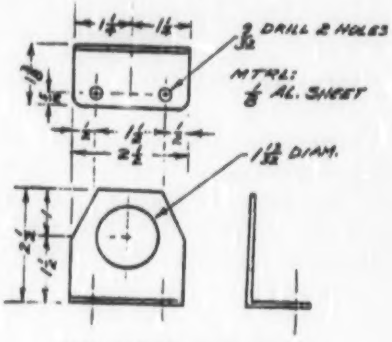
TABLE A-1. (Concluded)

NOTE 6:

Construct item No. 52 and 53 as shown:



CYLINDER SUPPORT BRACKET

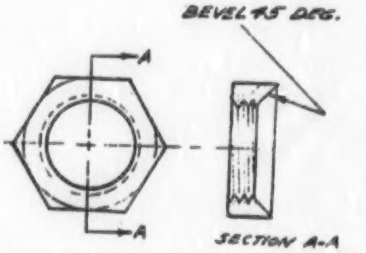
2 REQD.

NOTE 7:

Modify the nuts which are furnished with the tandem cylinder as shown here.

(An alternate mounting method is shown on the large drawing as regards the closed end of the tandem cylinder only. However, this is not preferred.)

MATERIAL FURNISHED AS PART OF PURCHASED CYLINDER.



CYLINDER SUPPORT NUT

2 REQD.

NOTE 8:

The pneumatically actuated system shown in Drawing AP-75-002 is applicable fpr construction of the mechanically actuated version (which is mounted on a backpack) by making the following substitutions:

Omit the following items: Item No. 4, 14, 62, 45, 47, 48, 6, 56, 11, 19, 17, 61, 15, 16, 20, 5, 12, 7, 60, 58, and 302.

Add the following items:
- One each, three-way palm button valve; Norgen No. D0023A (Teglon Eng., El Monte, CA)
- One each, control cable, standard automotive choke cable
- One each, handle with actuating lever
- One each, set of brackets
- One each, backpack frame
- (see photograph No. SA631-1/13/75-S1C)

NOTE 9:

The chemicals for filling the tandem cylinder are obtained in pressurizable cylinders from:

Olin Corp.
P.O. Box 847
Benicia Park
Benicia, CA. 94510

The chemicals are designated as No. 202-C1

The "fast" foam referred to in the text of this report has the designation: Olin No. X 721102.

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APPENDIX B

REFILLING THE FOAM DELIVERY SYSTEM

The following is a description of the equipment and of the procedure used to refill the foam delivery system. The baseline urethane foam system is designated No. 202-Cl by the Olin Company. Therefore, the instructions below were derived from information provided by that supplier. Instructions provided by the supplier of alternate foam systems should be obtained and followed where applicable.

DESCRIPTION

The flow diagram in Fig. B-1 shows the basic equipment normally used for refilling the portable foam delivery system tandem cylinders. The chemicals are contained in pressurized cylinders with the isocyanate component (or A component) color-coded WHITE and the polyol component (or B component) color-coded BLACK. Caution: These cylinders are under pressure when delivered.

The complete system (Fig. B-1) consists of component cylinders, which are pressurized by the nitrogen supply, causing material to pass through the component hoses, to the filters, and to the quick disconnects which are later plugged into the mating disconnects on the delivery system to be filled.

CHEMICAL PREPARATION HANDLING AND STORAGE

These are instructions from Olin Corporation for their use of the foam chemicals in their commercial foam delivery system.

Temperatures:

1. Material cylinders should never be stored at temperatures below 21 C (70 F) or above 32 C (90 F).
2. For optimum operation, material temperatures in the cylinders should be above 24 C (75 F) and below 32 C (90 F).
3. These temperature ranges are critical as they can affect the reactivity of the foam systems.

FLOW DIAGRAM

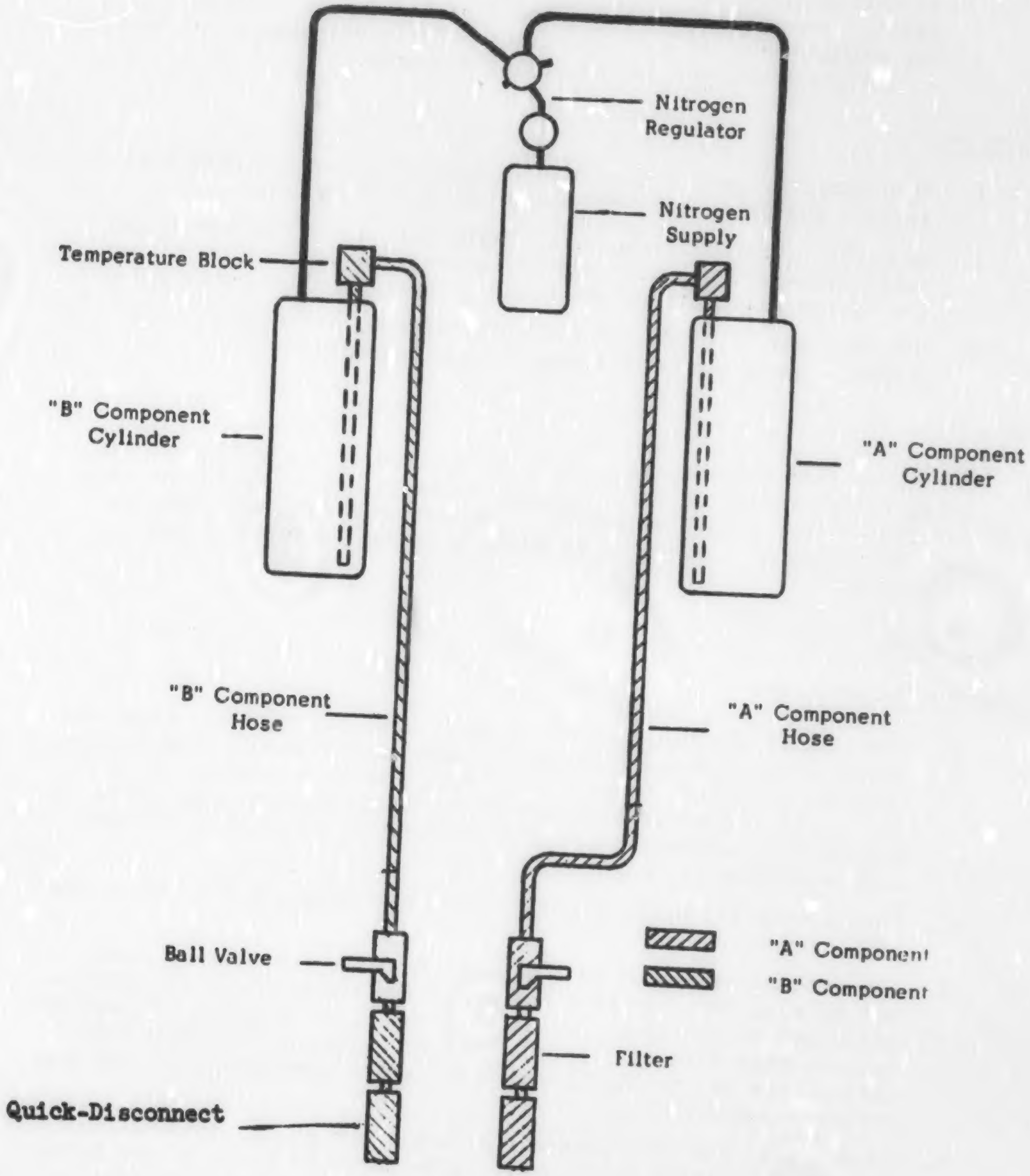
Nitrogen Regulator
Nitrogen Supply
Temperature Block
"B" Component Cylinder
"A" Component Cylinder
"B" Component Hose
"A" Component Hose
Ball Valve
"A" Component
"B" Component
Filter
Quick-Disconnect

Figure B-1. Schematic Diagram of Equipment to Refill Foam Delivery System

Mixing:

1. The Autofroth I foam chemicals (foam chemicals 202-Cl were used in this project) are completely premixed at the Olin producing plant. however, quantities should be ordered as indicated by the requirements of your operation. Cylinders should not be kept in investory for periods exceeding 6 months.

Nitrogen:

1. When properly used, one 220-cubic foot nitrogen cylinder will service approximately 1000 pounds of Autofroth foam.
2. When the nitrogen pressure, as indicated on the pressure gage, falls below 240 psi, replace or recharge the nitrogen cylinder. The system will not operate below a constant pressure of 220 psi.
3. USE ONLY DRY NITROGEN FOR CYLINDER PRESSURIZATION (i.e., oil pumped. Water-pumped nitrogen is not suitable).

CAUTION:

Excessive direct heat should never be applied to any cylinder. To bring the chemicals contained in the cylinders up to operating temperatures, they should be placed in a warm environmental room, or box, for a period sufficient to allow a gradual warming of the chemicals.

INSTALLATION

Cylinder Preparation:

1. Ensure that the two (one white and one black) material component tanks are placed together in the same environmental temperature. Chemical component temperatures should be at a minimum of 21 C (70 F) and a maximum of 32 C (90 F). Bear in mind that these temperature restrictions are parameters with the ideal temperature somewhere around 25 C (80 F).
2. Ensure that all ball valves on the material cylinders are in the off position.
3. Remove hexagon-shaped sealing caps from the top of each tank, making sure that the ball valve and dip leg assembly are held in place and do not turn. Clean with methylene chloride if required. Apply a thin film of silicone grease, vaseline, or other lubricating-type oil to the thread area before connecting the matching female assembly.
4. Ensure that the hose connections are tight at the gun and the filters. Position BLACK manifold temperature block on the black tank and complete the attachment with the disconnect fitting from the nitrogen tank. Position WHITE temperature manifold

block on the white tank and attach its appropriate nitrogen pressurization fitting. Tighten the nuts gently with a wrench until connectors are fully engaged. When fully engaged the manifold blocks will not rotate and the hose will not move. ALWAYS DOUBLE CHECK THE TANK COLOR-CODE BEFORE CONNECTING.

5. Cylinders should never be brought to higher temperatures while in a pressurized condition. If cylinders have been pressurized to the 250-psi working pressure, and it is determined that the foam chemicals must be further heated, IT IS IMPERATIVE THAT THE PRESSURE BE RELIEVED TO 75 PSI BEFORE HEATING. A 590-915 Pressure Relief/Transfer System is available for this purpose.
6. Ensure that the valves at the ends of the delivery hoses are turned off; then turn the ball valves on the cylinders to the open position.

Sealing Empty Cylinders for Return:

1. Always ensure that the sealing dust caps are tightly screwed onto the male connectors and the quick disconnector dust caps are in place on the tanks when they are not in use. This is essential to prevent possible contamination and vapor leak from the connectors. Make sure the threads and ball cage of all fittings are clean and well lubricated before replacing caps.
2. Empty cylinders returned for refilling must also be sealed, cleaned, and pressure relieved to 50 psi. Failure to seal the empty tanks upon return will result in additional servicing with such charges deducted from the tank deposit.

Nitrogen Connection:

1. Make sure all fittings and hose connections are attached and tightened to the nitrogen regulator.
2. With the valve on the nitrogen bottle in the open position, first connect the nitrogen to the white material tanks. A surge of nitrogen should be noted indicating that the pressure is building in that cylinder. This eliminates the possibility of a frozen tank fitting which occasionally occurs only on the white tank. Also, by connecting the fitting while the nitrogen is in the open position, this eliminates any chance of material from a full tank flowing into the connections.
3. Connect the remaining nitrogen lines to the rest of the system and pressurize until equilibrium of nitrogen pressures has been obtained. Ensure that there is 240 psi minimum on each cylinder and that there is a reserve of nitrogen in the nitrogen tank.
4. On the larger Autofroth cylinders there is a ball valve below the nitrogen tank fitting. Be sure the ball valve is turned to the open position during hook-up and when operating. Also ensure that you are using dry nitrogen ONLY.

OPERATION

When the recharging equipment is ready for use, but before connecting it to the system to be filled, obtain several disposable plastic bags for catching waste foam chemicals. Plug a spare quick disconnect into the end of each delivery hose (Part No. 35, Appendix A). This opens the check valves in the quick disconnects and will allow chemicals to flow out freely when the ball valves are opened. After placing the tip of the Chemical A delivery hose in a plastic bag, very slowly and carefully open the system A ball valve, allowing any trapped air or gas to escape from the delivery line and momentarily allowing the chemical following it to gush out. As soon as the chemical flows freely from the tip, close the ball valve and flush the chemical from inside the quick disconnect with solvent. Repeat the above for Chemical B delivery line. Now remove the spare quick disconnects from the tip of each delivery line and set them aside for cleaning and then storage. The above flushing operation needs normally to be done only when the equipment is new or after an extended time of several weeks inactive storage.

Actuate the delivery system to be filled to ensure that as much as possible of the residual chemicals remaining in the main cylinder have been expelled. (Be sure to remove the flushing hoses before proceeding to the next step.) Now connect the quick disconnects on the end of each fill line to the corresponding female quick disconnects on the delivery system after first checking to see that they have not been inadvertently reversed. The polyol should be connected to quick disconnect No. 35 and the isocyanate to quick disconnect No. 36.

> CAUTION: Should liquid A be allowed to flow into the liquid B system, the resulting reaction will render the system useless in a matter of seconds and the tandem cylinder probably will have to be discarded.

PAY ATTENTION TO THE COLOR CODE. Connect back to black (component B, polyol), and white to white (component A, isocyanate). (An obvious and simple manufacturing improvement would be to provide a foolproof method whereby it would be impossible for the operator to make the mistake mentioned above.)

Check that the cylinder on the delivery system has been vented. (Actuation Valve, Part No. 5, is in vent position). Now open the two ball valves nearly simultaneously, with component B leading component A by approximately 1 second. This will cause the shaft to travel out of the cylinder as the pistons are displaced by the incoming liquid chemicals. Allow the system to remain with the ball valves open for 3 minutes; then close them and carefully disconnect the fill lines at the quick disconnects.

Next, connect two bleed lines to the two quick disconnects (37 and 38). These bleed lines conduct excess material trapped between quick disconnects 33 and 37, and between 34 and 38 into waste containers provided for this purpose. This step is taken so that this material will not prematurely flow into the mixing subassembly when these units are interconnected later in the field. After waiting a few minutes for the chemicals to stop flowing out of the bleed lines, remove them.

Flush out the disconnects with solvent several times,* each time removing excess solvent by blowing out the disconnect with compressed air or nitrogen.

> CAUTION: This should be done under a hood or with good ventilation to prevent personnel from inhaling the fumes.

When first using a new system, the flowrate of nitrogen gas through the needle valve (8) should be checked with a flowmeter to be 30 scfh (standard cubic feet per hour) for the small delivery system and 45 scfh for the large delivery system at a pressurant level of 250 psig. If incorrect, adjust needle valve (8) until proper flow is obtained.

The delivery system is now recharged and ready for reuse.

MAINTENANCE

Component parts, whenever disassembled, should be thoroughly cleaned immediately in methylene chloride. If the part or the unit is not to be used for extended periods, apply a light coat of lubricating oil on the exposed portions of the system after a thorough cleaning.

The isocyanate, (i.e., component A, color-coded white) will react with the moisture in air in a matter of hours to form a very tough, solvent-resisting material. Do not let air enter components to be reused if at all possible. If air does enter, flush the delivery system by filling and emptying it twice.

> CAUTION: NEVER disconnect any hoses or other parts of the fluid system while hoses are connected to tanks and the cylinder ball valves are in the on position. Whenever temperature manifold blocks are removed from cylinders, be sure cylinder ball valves are in the off position.

To clean the filter, disassemble it, remove the filter screen, and flush thoroughly in clean solvent. Then, reassemble it.

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*Viton seals should be allowed to remain in contact with methylene chloride for as SHORT a time as possible to prevent swelling.